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PRINCIPLES AND PRACTICE OF PLUMBING

By J. J. COSGROVE

AUTHOR OF

Sewage Purification and Disposal
Sanitary Refrigeration and Ice Making
Rock Excavating and Blasting

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PREFACE

In preparing the manuscript for this book, the author's sole object was to systematize and reduce to an exact basis, the principles which underlie the practice of plumbing. The necessity for accurate rules and formulas, instead of the empirical methods formerly employed, was often and forcibly brought home to the author when designing plumbing installations for large buildings. The scarcity of scientific information on this important branch of sanitation was quite marked. No book had ever been published that indicated the best kind of material to use for a given purpose, that told how work should be designed and installed to be perfectly sanitary, and that showed how to proportion the various parts with relation to the whole, so that a plumbing system designed and installed according to the text would give perfect service.

Rules and formulas for proportioning hot and cold water supply pipes were entirely lacking and no literature was available that would be of assistance in determining this most important feature of a building. Neither could anything be had that would indicate the size of piping required to supply a given number of flushing valves for closets, nor that mentioned the numerous other conditions requiring consideration when designing a plumbing installation.

Realizing this, the author gathered much valuable data and worked out many rules and formulas from his private practice, and the gist of the rules, formulas and data have been incorporated in "Principles and Practice of Plumbing" where, for the first time, they were offered to the public.

In planning the scope of the book, it was assumed that the reader knew but little of the subject of plumbing, and had no source of information outside of the book. With this premise in mind an effort was made to prepare the subject matter so clearly and concisely that a person of average intelligence, by following the text, could design and proportion any plumbing installation. That this object has in a measure been realized is evidenced by the interest of architects, engineers and plumbers in the articles when they first appeared in serial form in MODERN SANITATION, and by the large domestic and foreign advance subscription for the work in book form.

It is the intention of the author and publishers to keep "Principles and Practice of Plumbing" the standard work on plumbing and sanitation, and to this end the book will be subject to revision when found necessary. Criticism of the subject matter will be welcome, as by fair and intelligent comment its value will be enhanced.

J. J. COSGROVE.

PREFACE TO SECOND EDITION

A second edition of "Principles and Practice of Plumbing" having been called for, a complete revision of the work seemed advisable to the author. Since the book was first published, it has been accepted as the standard work on plumbing in this country, and as such is used in over fifty colleges, universities and trade schools throughout the United States. Such a general acceptance of the work places upon the author the responsibility of keeping the book thorough and complete in every respect, and, as many changes have taken place in plumbing practice since the original manuscript was written, and numerous queries received since the book was published, have pointed out where additional matter could be supplied, the present revision, which amounts to a rewriting of the book, was decided upon that no matter of value would be omitted.

J. J. COSGROVE.

Philadelphia, Pa., 1914.

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PART I
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CHAPTER I
GENERAL CONSTRUCTION

Sanitation in modern building is given far more consideration than at any time in the history of architecture. Not only is this true in regard to the increased size of living rooms, the provision made for light and air, and the introduction of ventilation and heating systems, but more particularly in the wonderful improvements in plumbing, both as regards the drainage systems, the water supply and the fixtures. The improvements in workmanship, materials and the systems of installation have so changed the character of plumbing that new standards of comparison are required to determine the quality of work. For instance, while formerly plumbing fixtures were hidden in ill-ventilated, poorly-lighted, out-of-the-way places, and used only as necessities, they now occupy a prominent place in the household of the intelligent, and have become a luxury as well as a necessity.

The improvements in fixtures consist chiefly in substituting earthenware and porcelain enameled ware for the plain iron, copper and wood formerly used; the prohibition of all mechanical closets, with their large fouling chambers, and adopting instead closet bowls with traps combined that are vitreous, non-corrosive and non-absorbent both inside and outside; the connecting of all waste pipes from fixtures with a trap placed as close to the fixture as possible, and, not least in importance, the setting of all fixtures open in-

stead of boxing them in wood, thus doing away with the old incubators for vermin and catch-alls for filth.

The improvements in the systems of drainage within a building consist of the use of properly proportioned piping, the sizes of pipe being determined by calculation instead of by guess as of old; the perfecting of a system of ventilation to keep the air within the drains comparatively pure; improvement in the shapes of fittings; increased weight and better qualities of pipe used, and better methods of joining the pipes; these all contribute their share to the improvement of the system as a whole.

Results of bacteriological investigations having shown that more disease enters a building through the water supply than from the drainage system, certain precautions are taken to minimize the danger from this source. The source of the water supply is selected where there is least danger of contamination or infection, and care is taken to protect the water from pollution while in storage; also ample time is allowed for sedimentation and sunlight to remove bacteria before the water is delivered into the distributing mains. In some places the municipal supply of water is filtered through germ-proof filters before it is delivered to the consumers. Where this is not done separate house filters may be installed by consumers for their own protection.

EXAMPLE OF A DRAINAGE SYSTEM.—To those who are not familiar with plumbing, there is something complicated and bewildering, about an installation, which would seem to defy analysis. Anything, however, which is based on a system, is simple when the system is understood; and as plumbing work is all done according to well defined principles, the work is easy of comprehension to those who understand the underlying principles. In this work the effort will be made to rob plumbing of its mystery, and so present the explanation that anybody with a fair knowledge of building can properly plan work. In doing so, simple illustrations will be used, as simple illustrations show the system followed, which can then be applied to any kind or size of installation, while illustrations of large complicated installations would be so clogged with detail as to be bewildering.

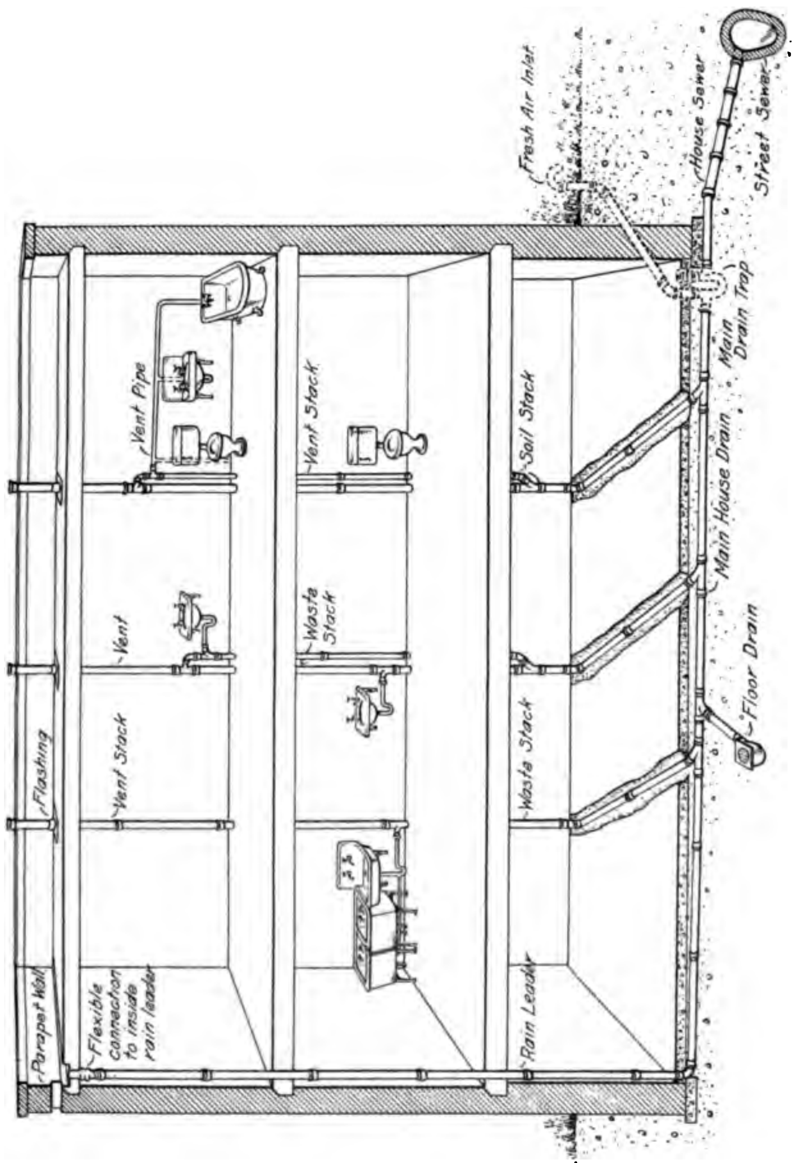


Fig. 1 - Complete Drainage System

In the illustration, Fig. 1, is shown in broken perspective the general layout of a plumbing system, which includes the principal elements of any and all systems. The object here is to show the various parts in relation to the whole. The various parts will later be examined and described in detail.

The drainage system, it will be seen, starts at the public sewer in the street. That portion of the horizontal drain extending to within a short distance of the foundation wall of the building is known as the house sewer. Inside of the foundation wall is a main drain trap and a fresh air inlet leading to the atmosphere outside. This trap and fresh air inlet it might be well to mention are better omitted; but as they are required by law in some cities, they are here incorporated as showing one of the possible elements in a system of plumbing. Continuing from the fresh air inlet there is the main house drain which is the horizontal system of piping in the basement or cellar of a building.

The house drain, as in the present example, may be run under the floor, may be run above the floor, or suspended from the ceiling overhead. All that is necessary is to have a positive fall towards the sewer, and run the pipes as direct as circumstances will permit. Otherwise the designer can use his own judgment as to how the pipe shall be run and where it will be located, there being no particular way or ways in which it must be done, nor particular places in which it must be located.

A floor drain is shown ready to drain the cellar floor. Floor drains are not advisable only in locations where their traps will always be sealed with water, but is shown here to indicate the manner they are installed. A rain leader is shown at the rear of the building. Like the main house drain, there is no particular way to run a rain leader, so long as it is run direct as possible and with a good fall towards the sewer. At the roof or gutter, the leader is shown connected with a flexible connection. This is necessary to take up the variations of length due to the "creeping" of the leader stack. Connections are shown taken off the main house drain for rising stacks of soil and waste

pipe. Here, again, the simple is the right thing to do. A "Y" fitting or "TY" fitting with straight direct run to the stacks is always preferable, although a drain can be offset around an obstacle when necessary, provided there is always a good drain to the pipe.

In the vertical stacks are shown three different methods of running lines. To the rear is a waste stack for the kitchen sink and laundry trays, which becomes the vent stack above the level of the fixtures. In the middle is a double line of waste pipes for a couple of lavatories located on different floors, while to the right is a stack of soil pipe with an accompanying vent stack. These stacks are all shown run close to the wall, although they may be run at any convenient place close to a partition but well away from the outside walls; concealed in partitions, or any other part of the building, the only consideration being to keep them as much out of the way and as much out of sight as possible.

It will be noticed that all of the vertical stacks of soil and waste pipes extend through the roof where they are open to the atmosphere. It will be seen, therefore, that air entering the fresh air inlet will keep flowing upward through the system of soil waste vent and leader pipes, so that the drain air within will be thoroughly diluted with fresh air from outside. It is obvious that placing a trap at the foot of any of these lines would stop the circulation through the lines so trapped, which would be very objectionable. For this reason traps are never used at the foot of any vertical lines of pipe except rain leaders when they open close to doors or windows.

If the main drain trap and fresh air inlet were omitted, there would still be a circulation of air through the system, but in that case, the air would first pass through the public sewers in the street, thereby keeping the air within as freely diluted as that in the drainage system.

The foregoing shows and explains the principal elements of a drainage system. The system might be larger, contain more stacks, leaders and branches, extend up through a greater number of stories, or be modified in some way as will be explained in detail further on. No matter

how complicated the system may be, however, it can be divided up into the house drain; stacks of soil, waste and vent pipes; and the fixture branches from the stacks; and these can be laid out by remembering the few fundamental requirements for the various elements.

REQUIREMENTS OF A PLUMBING SYSTEM.—First—An adequate supply of water sufficient in volume and pressure to flush all the fixtures at one and the same time.

Second—Types of fixtures that are made of porcelain, porcelain enamel or some other non-absorbent material are set open, and located in well lighted, properly ventilated rooms.

Third—A system having waste pipes large enough to carry off all waste matter discharged into them, yet not so large as not to be self-cleaning.

Fourth—A system of ventilation so planned as to properly ventilate every portion of the drainage system and provide relief in tall buildings for the heaved-up air in soil stacks when a number of fixtures are in use at the same time.

Fifth—A quality of piping that will neither corrode easily nor be affected by sudden changes of temperature, and the joints of which can be made as strong as the pipes themselves.

Sixth—A properly graded, perfectly gas and water-tight system that will discharge by gravity.

Seventh—A system so supported throughout its entire extent, and so provided with swing joints and flexible connections as to take up the shrinkages, settlements and temperature changes of the piping and building without damage to the fixtures, connections, piping or buildings.

Eighth—A system of installation that provides turns and offsets of easy angles; in which the branches are connected so as not to interrupt the flow of sewage in the main, and that provides clean-outs at such points that the inside of the drainage system is accessible throughout its entire extent.

CHAPTER II
THE HOUSE SEWER

Plumbing systems for buildings consist of the drainage system and the system of water supply. Drainage systems include the house sewer, house drain, soil waste and vent stacks, branch fixture-connections and fixtures. Also in some cases the subsoil drainage.

The house sewer is that portion of the drainage system which extends from the street sewer or other place of sewage disposal to a point not less than five feet outside the foundation wall. It receives the discharge from the house drain rain leaders, yard and area drains, and in some cases from the subsoil drains.

House sewers are generally made of tile pipe, although cast-iron pipe is sometimes used. When constructed of tile pipe, the pipe should be straight, cylindrical, smooth, free from cracks, perfectly burned, and should have a good salt glaze over the entire inner and outer surfaces, except the inside of hubs and the outside of the spigot end, which should be left unglazed, otherwise cement will not adhere to the pipe and an imperfect joint will result.

Tile pipe is made in all standard sizes corresponding to iron pipe sizes up to 36 inches in diameter, and are made in several different weights. In Table I are shown the various sizes, weights and dimensions of standard weight tile sewer pipes. The sizes, dimensions and weights of double strength tile sewer pipe can be found in Table II. Ordinarily, tile pipes are made in lengths of 2 feet each, from inside of socket to end of pipe so that each length will lay just 2 feet of pipe. Special lengths of tile are made, however, 3 feet long, and these are better than the two-foot lengths for sewer purposes, as they reduce almost 50 per cent. the number of joints in a sewer.

Deep and wide socket tile sewer pipes are likwise made. That is to say, whereas in ordinary standard 4-inch sewer pipe the depth of the hub is only $1\frac{1}{2}$ inches, with an annular

space of 1/4 inch between the inside of the hub and the outside of the spigot inserted in the hub, in the deep socket pipe, the hubs of 4-inch pipe are 2 inches deep with a space of 1/2 inch between the inside of the hub and the outside of the pipe. This greater depth of hub and width of space makes possible a better joint so that deep wide socket tile pipes 3 feet in length would be the best to use where a water tight sewer is required. The weights and dimensions of standard deep and wide socket pipes can be found in Table III, while the weights, dimensions, and depth of sockets of double strength deep and wide socket pipes can be found in Table IV.

TABLE I. Dimensions of Standard Sewer Pipe

Calibre Inches	Thickness Inches	Weight per Foot Pounds	Depth of Sockets Inches	Annular Space Inches
3	1/2	7	1 1/2	1/4
4	1/2	9	1 5/8	3/8
5	5/8	12	1 3/4	3/8
6	5/8	15	1 7/8	3/8
8	3/4	23	2	3/8
9	13/16	28	2	3/8
10	7/8	35	2 1/8	3/8
12	1	43	2 1/4	1/2
15	1 1/8	60	2 1/2	1/2
18	1 1/4	85	2 3/4	1/2
20	1 3/8	100	3	1/2
21	1 1/2	120	3	1/2
22	1 5/8	130	3	1/2
24	1 5/8	140	3 1/4	1/2
27	2	224	4	3/4
30	2 1/8	252	4	3/4
33	2 1/4	310	5	1 1/4
36	2 1/2	350	5	1 1/4

METHODS OF LAYING TILE SEWER.—The usual method of laying tile house sewers is to dig a trench from the street sewer to the house that is to be connected, grading the bottom to as nearly the required slope as possible and laying the pipe on the bottom of the trench. Where the grading is imperfectly done, the pipe must be blocked up in the low spots to the required grade before the joints are made. The joints are made by filling the hubs with mortar made of equal parts Portland cement and sand. When drains are

thus installed, the bracings under the pipes are seldom sufficient to hold the pipe in position while the trench is being filled, consequently, the joints are very apt to be broken.

A good method of laying tile pipe is to so dig the trench that the bottom will have a proper and uniform grade, then, by scooping out where the hubs come, the pipe can be laid with a good bearing its entire length on undisturbed earth. This method, when properly carried out, is unquestionably the best known method of laying tile pipe, but great care must be taken in digging the trench so as not to spoil the bearing for the pipe by digging below the grade.

TABLE II. Dimensions of Double Strength Pipe

Calibre Inches	Thickness Inches	Weight per Foot Pounds	Depth of Sockets Inches	Annular Space Inches
15	1¼	75	2½	½
18	1½	118	2¾	½
20	1⅔	138	3	½
21	1¾	148	3	½
22	1 5/6	157	3	½
24	2	190	3¼	½
27	2¼	265	4	¾
30	2½	290	4	¾
33	2⅝	335	5	1¼
36	2¾	375	5	1¼

A quick method of laying tile pipe is to dig the trench to the proper grade and bed a line of planks firmly on the bottom; then lay the drain on the planks. By this method the time of leveling each length of pipe is saved, also the time excavating for the hubs, and if the planks are properly graded, the drain is bound to have a proper and uniform fall. Some authorities advocate the bedding of tile pipe in six inches of concrete, but as the concrete would increase the cost of a tile drain to more than the cost of an iron one, it would be better to install an iron drain instead.

LEVELING TILE PIPE.—The method usually adopted for leveling tile pipe is to place an ordinary spirit level on each length of pipe as it is laid, and raise or lower the free end of

the pipe until the level shows it to be at the required grade. The objection to this method is that unless the end of each length of pipe is properly centered in the preceding hub each length might have a good fall while the entire drain might be level. A better way is to level from the hubs of the pipe. When these are properly graded and the spigot ends of each length of pipe blocked to the required height, the entire drain will have a true and uniform fall.

A straight edge long enough to reach at least four of the hubs should be used to level drains. A good straight edge for this purpose can be made by cutting a straight dry piece of white pine six feet long, and jointing the edges per-

TABLE III. Weights and Dimensions of Standard, Deep and Wide Sockets

Calibre Inches	Thickness Inches	Weight per Foot Pounds	Depth of Sockets Inches	Annular Space Inches
4	1/2	10	2	1/2
5	5/8	12	2 1/2	5/8
6	5/8	16	2 1/2	5/8
8	3/4	25	2 3/4	5/8
10	7/8	37	2 3/4	5/8
12	1	45	3	5/8
15	1 1/8	70	3	5/8
18	1 1/4	90	3 1/4	5/8
20	1 3/8	115	3 1/2	5/8
21	1 1/2	130	3 5/8	5/8
22	1 5/8	145	3 3/4	5/8
24	1 5/8	150	4	5/8

fectly straight and square with the sides. It should be made as much wider at one end as there will be fall in six feet of the sewer; then, by placing the straight edge on the top of the hubs with the wide end toward the outlet, the top of the straight edge will be level when the sewer has the required fall.

Most tile pipes are warped a little in burning, so that the lengths are not perfectly straight. Care should be taken, therefore, when laying a tile sewer to see that the bend in crooked lengths is placed at the side and not at the top or bottom, where they would form a series of shallow pools for the retention of sewage.

When the tile sewers are laid on planks that are properly graded, all that is necessary is to block up the spigot ends in the hubs. The pipes will need no further leveling.

TILE PIPE JOINTS.—The usual methods of joining tile pipes is to fill the annular space between the hub and spigot with cement mortar and bank it full in front of the joint.

When the inside of the hubs and the end of the pipes are unglazed, this method makes a very fair joint. However, most tile pipe now made have both hub and spigot salt glazed, consequently, under such conditions, mortar will not adhere to the pipe and the joints soon leak.

Salt glazed pipe can be made water-tight by first calking the hub half full of oakum that has been dipped in cement grout, and then cementing the joint as in the first instance. The oakum should not be loosely packed in the

TABLE IV. Weights and Dimensions of Double Strength, Deep and Wide Sockets

Calibre Inches	Thickness Inches	Weight per Foot Pounds	Depth of Sockets Inches	Annular Space Inches
15	1¼	75	3	⅝
18	1½	118	3¼	⅝
20	1⅔	138	3½	⅝
21	1¾	148	3⅝	⅝
22	1 5/6	157	3¾	⅝
24	2	190	4	⅝

hub, but should be calked in hard enough to make the joint water-tight; the cement gives the joint the necessary strength. When tile pipe joints are made with cement mortar without first calking the joints with oakum, great care should be exercised to remove any cement that might be worked through to the inside of the pipe. The cement can be removed by placing in the drain a large swab that completely fills the bore of the pipe, and drawing it along a couple of feet each time a length of pipe is laid.

The pipe joints are sometimes made with asphalt; the joints are first made tight by calking with oakum and then

poured full with hot asphalt. For many purposes asphalt joints are preferable to cement joints; they are lighter, more flexible, and not so likely to be broken by a settlement of the ground or by jarring of the pipe when the trench is being filled.

Tile pipe joints can likewise be made with "Leadite" and will withstand an internal pressure of 5 to 7 pounds or more without leaking. Leadite is a lead-like material which is poured while in a molten condition into the hubs. Unlike lead, it expands slightly upon cooling, thereby filling all the little cavities and crevices of the hub and spigot, making them tight without calking. All that is necessary in making a Leadite joint is to calk the hub first with oakum, then pour the Leadite.

WHERE TILE SEWER PIPE MAY BE USED.—Tile pipe should be used for house sewers only when a natural bed of earth or rock can be obtained to lay it on. It should not be used even then if it is exposed to frost, discharges into a cesspool or passes near a well, spring or other source of water supply. The chief objection to the use of tile pipe for house sewers is the unsatisfactory joints between the lengths. During dry weather or in localities where the ground water is low, sewage escapes from the sewer into the earth and might wear a channel to some nearby well, cistern, or other source of water supply. During wet weather, or in localities where the ground water is high, water enters the sewer through the joints, a condition that might prove expensive in case the sewage is treated at a disposal plant.*

Another not uncommon source of trouble from leaky joints are roots of trees that enter in search of water and in course of time completely obstruct the drain.

PIPING FOR ALKALI AND ACID WASTES.—Although tile pipe as a rule is not so desirable as cast iron pipe for house sewers, and is seldom satisfactory for a main house drain, there are conditions under which it is better than ordinary soil pipe, but not so good as high-silica cast-iron pipe.

*At Grinnell, Iowa, the flow of sewage in wet weather is from three to four times the volume of water pumped from the city wells. No permanent water level, steepage at depths varying from 10 to 40 feet.

In chemical works, soda works, print works, plating works and other industries where iron pipe is destroyed by the acid, tile pipes will prove the better material when properly laid. In such cases the tile drain might well be bedded in concrete 6 inches thick, with 1 inch of cement mortar immediately surrounding the pipe. Where necessary to run vertical pipes to vats, or overhead horizontal pipes, the concrete can be reinforced and tile pipes used.

This makes a costly installation and, should the joints open, the acids will attack the concrete, which then fails in time. The glaze on tile pipe will resist most commercial acids, but when the glaze is gone, the biscuit ware forming the body of the pipe proves less resistant.

CAST-IRON ACID WASTES.—Soil pipe and fittings, in all commercial sizes of ordinary extra-heavy cast-iron pipe, also a special size 1½ inches in diameter, with a full line of soil-pipe fittings, are now made from high-silica cast iron, which will resist all commercial acids, but not sodas or other alkalies. The high-silica soil pipes are put out under trade names like "Duriron," and are put together with lead calked joints. Instead of oakum, asbestos rope is used as a packing. "Duriron" is an iron silicide containing about 14.5% Silicon, .8% Carbon, and .35% Manganese, and possesses physical properties as follows:

Melting Point	about 2300 Fahr.
Specific Gravity	7.00
Weight per cubic inch	0.253 lbs.
Hardness (Shore Scleroscope)	49 to 51
Contraction allowance in cast	3/16" per ft.
Coefficient of expansion	.00001565 per deg. Fahr.
Compression strength	70,000 lbs. per sq. in.
Tensile strength	10,000 lbs. per sq. in.
Transverse strength	1000 lbs. with deflection between 1/16 and ⅛ in.

"Duriron" is a cast metal, extremely hard and close grained. It shows a white fracture and takes a high polish. It will not soften materially nor lose its shape at a temperature a little below its melting point, and shows practically no oxidation at this temperature.

Owing to its extreme hardness, high-silica cast iron cannot be machined with cutting tools, but is finished by grinding. The high-silica pipes now on the market contain as high as 14.5% of silica. When the percentage reaches 16, the pipes will be immune to all acids. Report of a Government test on "Duriron" can be found in Table V.

"Duriron" sinks, vats, kettles and other acid-resisting containers are also made.

TABLE V. Report on Corrosive Tests on Duriron

By U. S. Bureau of Standards, April 24, 1920.
Cold Corrosive Tests (15° to 20° C) Duration, 120 Days.

Solution and Concentration by Weight	Area of piece in Sq. Cm.	Original Weight Grams	Loss in Weight Grams	Loss in Wt. Mg. per Sq. Cm.	Percent Loss	Depth of Corrosion In. per Yr.
Sulphuric acid 95%	67.69	116.5601	.008	.12	.007	.0000206
Sulphuric acid 25%	66.15	109.5050	.018	.27	.016	.0000463
Sulphuric acid 10%	65.34	103.4191	.026	.40	.025	.0000685
Nitric acid 70%	66.60	108.7927	.007	.11	.006	0000188
Nitric acid 25%	64.95	108.4709	.008	.12	.007	.0000206
Nitric acid 10%	65.81	110.4582	.000	.000	.000	none
Hydrochloric acid 25%	65.50	107.5262	3.078	46.99	2.862	.00805
Hydrochloric acid 5%	65.35	106.1607	1.234	18.90	1.162	.00324
Acetic acid 99%	66.63	111.9367	.007	.11	.006	.0000188
Phosphoric acid 87%	66.98	111.7125	.007	.11	.006	.0000188
Phosphoric acid 25%	66.31	113.7571	.011	.17	.010	.0000292
Phosphoric acid 10%	66.25	111.3789	.009	.14	.008	.000024
Oxalic acid 7.9%*	67.20	112.9180	.016	.24	.014	.0000412
Oxalic acid 2.1%†	66.49	109.4271	.014	.21	.013	.000036
Alum 15% cryst*	66.92	114.4460	.007	.11	.006	.0000188
Picric acid 9.1%‡	64.62	103.9213	.005	.08	.005	.0000137
Copper sulphate 25% cryst	67.49	117.8332	.009	.13	.008	.0000223
Ammonium Chloride 27%	65.05	103.1788	.037	.57	.026	.0000977
Ferric Chloride 48%	65.49	111.2925	.015	.23	.013	.0000395
Ferric Chloride 7%	66.42	113.6637	.018	.27	.016	.0000463
Oleic acid, comml	65.84	108.9583	.003	.05	.003	.00000857
Bromine, C. P	65.92	107.4264	19.785	300.14	18.42	.0515
Pyrogallic acid 31%	65.28	109.0550	.008	.12	.007	.0000206

*Saturated solution at 20° C. †¼ Sat. Sol. at 20° C. ‡Sat. Sol. in ethyl alcohol

Lead has been used to some extent for acid wastes, also lead-lined iron pipes. Lead is suitable for only a few acids, however, and there is a weak spot at every joint where the continuity of the lead lining is broken.

The comparative resistance of "Duriron" and other metals to various acids is shown in Table VI. This shows in

TABLE VI. Resistance of Various Alloys and Metals to Acids

Acid		Lead	Lead Antimony	Copper	Aluminum	Copper Alum. Alloys	Nickel Copper Alloys	Cast Iron	Wrought Iron	Dur. Iron
25% by Volume Sulphuric Acid	Percent loss in weight	.060	.044	.566	Diss.	.037	1.62	Diss	Diss.	.025
	Depreciation mg. per sq. cm.	1.412	1.015	9.42	"	.71	47.7	"	"	.35
	Depreciation grams per sq. in.	.0087	.0063	.058	"	.0044	.295	"	"	.00217
Concentrated Nitric Acid	Percent loss in weight	Dissolves	47.1	Diss.	Diss.	Diss.	Diss.	Diss.	Diss.	.0 5
	Depreciation mg. per sq. cm.	"	1100.0	"	"	"	"	"	"	.063
	Depreciation grams per sq. in.	"	6.82	"	"	"	"	"	"	.00039
Concentrated Hydrochloric Acid	Percent loss in weight	36.1	2.52	14.5	Diss.	23.2	14.91	Diss.	Diss.	3.93
	Depreciation mg. per sq. cm.	840.0	56.3	240.0	"	442	440	"	"	61.0
	Depreciation grams per sq. in.	5.208	.349	1.488	"	2.74	2.728	"	"	.3782
Glacial Acetic Acid	Percent loss in weight	3.29	3.18	3.17	.052	.590	.263	3.29	7.96	none
	Depreciation mg. per sq. cm.	77.6	73.9	51.0	3.0	10.91	6.95	51.1	82.8	none
	Depreciation grams per sq. in.	0.481	.458	.316	.0186	.0676	.043	3.168	.513	none

Weight of Duriron { 0.253 lb. per cubic inch; 4.048 oz. per cubic inch; 114.760 grams per cubic inch

Note—To change milligrams per sq. cm. to grams per sq. in. multiply by .0062.
Test 24 hours at 90°—100° F.

percentage the loss in weight of the various metals when exposed to sulphuric, nitric, hydrochloric and acetic acids. These four are the ones most commonly encountered in laboratory work, so it would be necessary for a waste pipe from a laboratory sink to resist all of them.

The various lead pipes are fairly satisfactory with sulphuric acid, but are violently attacked by nitric, and to a less extent by hydrochloric and acetic acids. Copper will not withstand any of the acids mentioned, and aluminum does only fairly well with acetic. Cast iron and wrought iron are not so violently attacked by acetic acid, but are dissolved in a short time by the other acids. High-silica pipe, on the other hand, is highly resistant to all the acids mentioned.

FIBRE CONDUIT FOR ACID OR ALKALI.—High-silica cast iron will not resist alkali or soda wastes. There is, however, a composition fibre conduit made by the Fibre Conduit Company, Orangeburg, New York, which will resist both acids and alkalis. The conduit was designed originally for the construction of underground electric subway systems, but has been found adapted to the waste from sinks in chemical laboratories. Pipe and fittings are put together with screw threads by means of couplings, and an acid-alkali-proof compound. A group of those fittings can be seen in Fig. 2.

IRON PIPE HOUSE SEWERS.—An iron pipe house sewer possesses many advantages over a tile pipe sewer. It is not so easily broken by settlement of the earth; the joints are perfectly gas and water tight and can not be broken by carelessness in filling the trench; the sewer is not so likely to be affected by upheavals from frost; it can safely be laid close to wells, cisterns or other sources of water supply, in any kind of soil, and it costs but a trifle more than the tile pipe sewer. Iron pipe sewers should be constructed of cast iron pipe; wrought iron or steel pipes are not suitable for this purpose, owing to their comparatively short life when buried in the earth.*

*See appendix for length of life of cast-iron and wrought pipe when buried in soil.

Cast-iron pipe sewers may be standard or extra heavy in weight, and either plain or coated. Coated pipe is covered both inside and out with a protective coating of pitch or asphalt, applied hot. This coating is beneficial in many ways—it prolongs the life of the pipe by protecting it from contact with the earth and sewage, and reduces the frictional resistance by forming a smooth surface. At the same time the coating helps to conceal sand holes and other defects, for which reason the pipe is better installed uncoated.

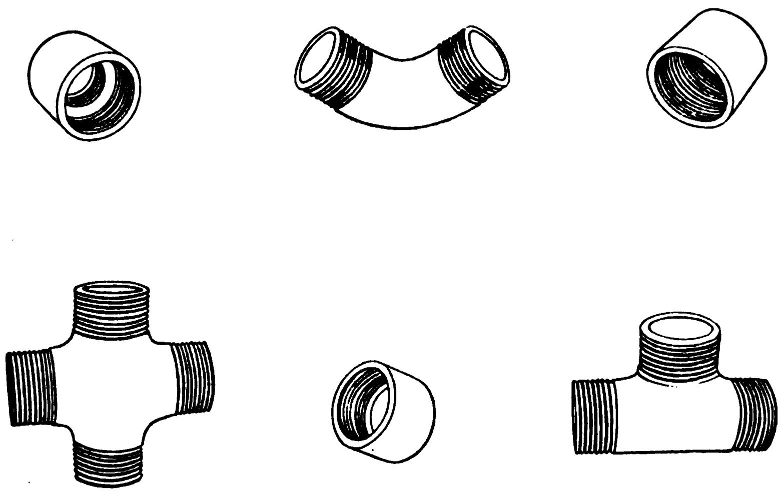


Fig. 2—Fibre Fittings for Acid Alkali Wastes

Cast-iron pipe should be sound, cylindrical, smooth, free from cracks, sand holes or other defects, of a uniform thickness and of the average weights per lineal foot shown in Table VII.

Standard weight pipe can be made tight when great care is exercised in cutting the pipe and calking the joints. Nevertheless, it should be used only on the smaller and less important of installations.

Cast-iron fittings should conform in all respects to all requirements of their respective grades of pipe.

Joints of cast-iron pipe may be lead calked, leadite poured, lead wool calked or made with rust joints.

LEAD CALKED JOINTS are made by calking a ring of oakum tightly into the hub of a pipe or fitting, and then filling the hub with molten lead. The lead contracts in bulk on cooling, and must be calked to expand it against pipe and hub to make a gas- and water-tight joint. Three-quarters of a pound of pure soft pig lead for each inch in diameter of the pipe is found sufficient for each joint under ordinary conditions; however, when a cut piece of pipe is being calked, a greater depth of lead is needed to compensate for the loss of the ring on the spigot end of the pipe. Two ounces of oakum are likewise required for each inch in diameter of the pipe.

TABLE VII. Sizes and Weights of Cast-Iron Pipes

Inside Diameter of Pipe	Average Weights per Lineal Foot, Including Hubs	
	Standard	Extra Heavy
2 inches	3½ pounds	5½ pounds
3 inches	4½ pounds	9½ pounds
4 inches	6½ pounds	13 pounds
5 inches	8½ pounds	17 pounds
6 inches	10½ pounds	20 pounds
7 inches	13 pounds	27 pounds
8 inches	18 pounds	33½ pounds
10 inches	25 pounds	44 pounds
12 inches	30 pounds	54 pounds
15 inches	45 pounds	....

RUST JOINTS are used in the drainage systems of chemical works, where the acids would affect lead joints; also they are used in cases where a line of pipe will be subjected to such a range in temperature that the alternate expansion and contraction would work lead out of the joints.

Rust joints are made by calking a ring of oakum into the hub, and filling the hub with a mixture composed of:

Flour of sulphur	1 part
Sal-ammoniac	1 part
Iron borings	98 parts

When a slow-setting rust mixture is desired, 198 parts of iron chips are used in place of 98 parts. A preparation

is now sold ready to use under the trade name "Smooth-on," which is easier to apply, quicker to set, and is stronger than rust joint. While it is more costly than a rust mixture, it is cheaper to use in the end on account of the greater quantity of work that can be done by its use, and the time saved in mixing the ingredients.

CONNECTION TO STREET SEWER.—House sewers should be connected to street sewers at an angle of about forty-five degrees, except in the case of large brick street sewers, when the house sewer may enter at right angles. Connections to brick sewers should be made at the side just above the springing line of the arch. They should never be made below the water line in the sewer. In tile street sewers, Y branches are usually provided at intervals of about twenty-five feet. to which house sewers may be connected. When branch connections are omitted in the street sewer a length of pipe should be removed at the proper location and a Y branch substituted. A hole should never be cut in a tile street sewer for the house sewer to be connected into.

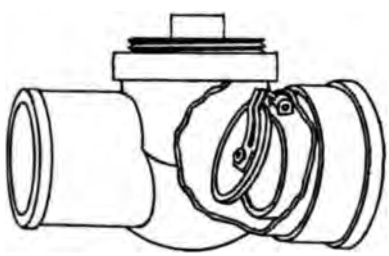


Fig. 3
Back Water Trap

House sewers discharging into tide water should enter below the low water level, and a vent should be placed in the sewer above the high water level to prevent tide water from air locking the sewer. When a plumbing system that drains into tide water is at so low a level that high tide will overflow some of the fixtures or fill the house sewer, a tide water trap, Fig. 3 should be placed on the end of the sewer to prevent tide water entering the pipe.

The usual practice is to make the house sewer one or two sizes larger than the house drain. A better practice, however, is to continue the house sewer the same size as the house drain. By so doing, a uniform velocity of flow is secured in both, and, when the house drain is rightly proportioned, a scouring action is assured.

CHAPTER III

HOUSE DRAIN

DEFINITION OF A HOUSE DRAIN.—A house drain is the system of horizontal piping inside of the cellar or basement of a building, that extends to and connects with the house sewer. It receives the discharge of sewage from all soil and waste lines, and sometimes rain water from rain leaders, yard, cellar, area and sub-soil drains.

House drains are generally located below the cellar or basement floor, where they are entirely out of the way. When properly installed with suitable materials and with clean-out plugs extending flush with the floor, there is no objection to this method of installation. In some buildings where the house drain is to be located below the floor, brick ducts with removable covers of iron or stone are provided to encase it.

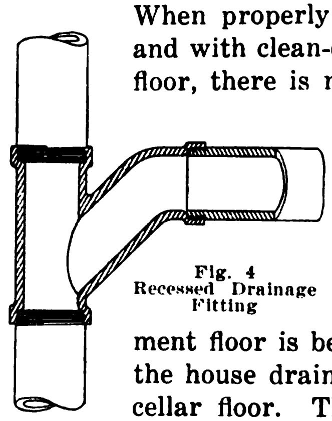


Fig. 4
Recessed Drainage Fitting

In buildings where the basement floor is below the level of the street sewer, the house drain is of necessity located above the cellar floor. The only objection to this method of installation is the fact that the network of pipes forming the house drain interferes with the head room of the cellar.

MATERIALS FOR THE HOUSE DRAIN.—When buried in the earth, house drains should be constructed of cast-iron pipe. In buildings over two stories in height they should be made of extra heavy cast-iron pipe; in small cottages standard pipe may be used.

House drains located in ducts or suspended above floors may be of wrought pipe with special cast-iron recessed drainage fittings which present smooth, continuous inner surfaces to the flow of sewage, as shown in Fig. 4. The wrought pipe and cast-iron fitting, should be coated

with asphalt, sherardized,* or galvanized both inside and out, and the ends of all pipes that screw into fittings should be reamed to remove the burr formed by cutting. Tile should be used in the construction of a house drain only in the cases pointed out in the paragraphs on house sewers.

CONNECTIONS TO HOUSE DRAINS.—Connections to house drains should be made with Y fittings, as shown at *a* in Fig. 5. A Y fitting gives the branch *b* an angle of forty-five degrees, and if it is to be run parallel with the main drain or at right angles to it, the change of direction can be effected by using a one-eighth bend, *c* or *d*. A T fitting should never be used in any part of a drainage system which

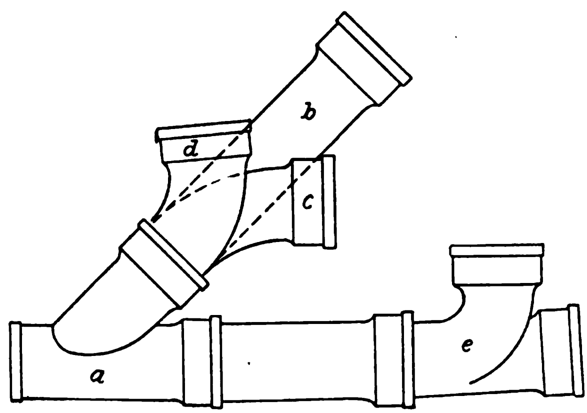


Fig. 5
Adaptability of Soil Pipe Fittings

receives the discharge of sewage, although they may be used in connection with the vent pipes. A TY fitting, *e*, if made with large sweeping curve so that it is almost equal to a Y fitting and one-eighth bend, may be used in any part of the drainage system. Short curve TY fittings, however, should never be used in a horizontal drain, although they may be used on the vertical stacks of soil and waste pipes. The end of a long horizontal drain where it turns up to form a soil or waste stack may well terminate with a clean-out plug in the end of a Y fitting, as shown in Fig. 6, with the branch of the Y forming the stack connection. If, how-

*Sherardizing process for protecting metals is explained in appendix.

ever, the horizontal drain is but a short branch of the main drain, or is a rain leader, a heel rest quarter bend, similar to Fig. 7, with a radius of over three or four times the diameter of the pipe may be used. Saddle hubs should never be used for connecting to any part of the drainage system. Changes in the direction of horizontal drains should be made at angles of forty-five degrees, or with large radius quarter bends.

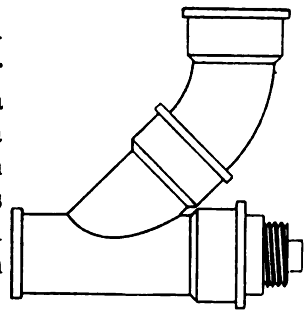


Fig. 6
Y Fitting and One-Eighth Bend

CLEAN-OUT FERRULES.—A clean-out ferrule is a metallic sleeve or ferrule calked into the hub of a soil pipe or fitting, and having a removable plug which can be taken out when necessary to gain access to the inside of the drain. A clean-out ferrule is shown in Fig. 8.

The body of a clean-out ferrule is made of brass or cast-iron; fittings of either metal may be used, although cast-iron clean-out ferrules are the better. They are thicker, heavier, more rigid and easier to make tight than brass ferrules, and not so easily bent out of shape when being calked. The plug for clean-out ferrules should be of brass, at least one-quarter inch thick, and the engaging parts have at least six standard iron pipe threads; also they should have a square or hexagonal nut, at least one inch high and one and one-half inches in diameter, so that the nut can be firmly gripped by a wrench when necessary to tighten or unscrew the plug.

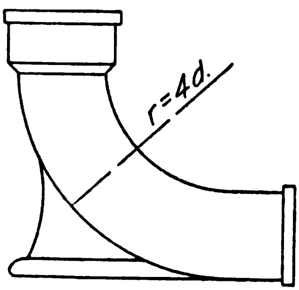


Fig. 7
Long Sweep Quarter Bend With Heel Rest

When clean-out plugs are set flush with the floor, instead of a nut, the screw plug should have a countersunk socket.

Clean-out ferrules up to five inches in diameter should be the full size of the pipes, and should be so located in a

system of house drains that the interior of the entire system, from the street sewer to the farthermost branch, will be accessible. A full sized clean-out ferrule should be calked in the end or branch hub of a Y fitting placed in the house drain where it enters the building as shown in Fig. 9, so in case of stoppage in the house sewer a rod can be pushed clear through the house sewer to the street sewer to dislodge the obstruction. In waste pipes from kitchen or scullery sinks, or other fixtures in which large quantities of grease are emptied, clean-out ferrules should be provided about every ten feet along horizontal runs through which to remove grease which, when chilled, adheres to the sides of the pipes to such an extent as to sometimes completely close the bore. Clean-out ferrules should also be provided in all main drains, yard, area or rain leader traps, but are never required in verticle stacks of pipes. Before a clean-out plug is screwed into its ferrule the threads should be lubricated with graphite. This is to prevent the threads from corroding and sticking when the plug is to be removed.

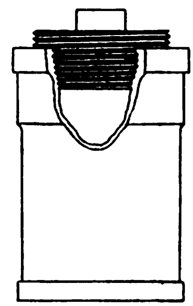


Fig. 8
Clean-Out Ferrule

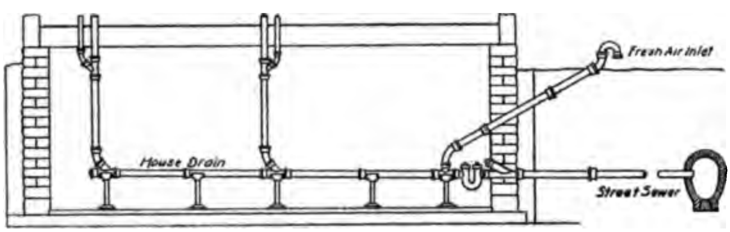


Fig. 9
House Drain

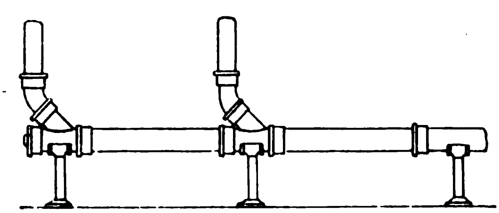


Fig. 10
Supports for House Drain

SUPPORTS FOR HOUSE DRAINS.—House drains above the cellar floor should be firmly supported throughout their entire extent by rests or hangers spaced about ten feet apart and placed near the hubs and under branch fittings for raising lines. When the house drain is run close to the cellar floor, brick piers or pipe rests as shown in Fig. 10, are generally used; when run some distance above the floor, the drain may be secured to the side wall by rigid pipe hangers similar to the ones shown in Fig. 11, or by pipe brackets similar to the one shown in Fig. 12, which ought to be secured to the masonry by means of expansion bolts. When run near the ceiling, the drain should be supported by iron pipe hangers fastened to the beams overhead. If iron beams support the ceiling overhead, hangers with beam clamps similar to that shown in Fig. 13 may be used. If, on the other hand, the building is of wooden floor construction, hangers with lag screws similar to that shown in Fig. 14 may be used. Pipe hooks should not be used to support the house drain, because they are not sufficiently strong or reliable.

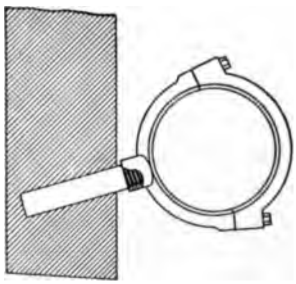


Fig. 11
Rigid Pipe Hanger

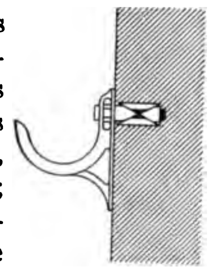


Fig. 12
Pipe Bracket

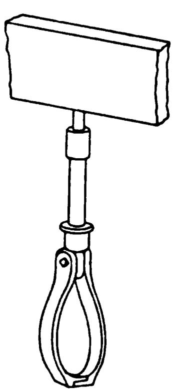


Fig. 14
Adjustable Pipe Hanger for Wooden Beams

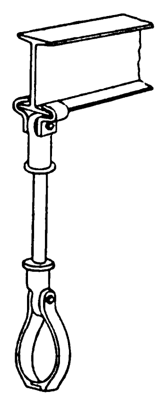


Fig. 13
Adjustable Pipe Hanger for Iron Beams

In reinforced concrete construction, screw sockets are attached to the forms so they will be cast in the concrete and hanger rods can be screwed into them.

MAIN DRAIN TRAP.—A main drain trap is seldom, if ever, necessary in plumbing practice for sanitary reasons, although they are legally necessary in some cities, being required by their codes. Where for any reason a trap is required it should be located inside of the foundation wall in an accessible position and as close to the wall as practicable. The only fitting intervening between the main drain trap and the foundation wall should be a clean-out Y. When there is no cellar under a building, the trap should be placed outside of the foundation wall below frost level and a brick manhole built around it to make it accessible.

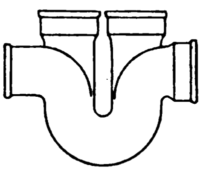


Fig. 15
Main Drain Trap

A main drain trap should have two clean-out hubs as shown in Fig. 15, in which to calk clean-out ferrules; and these hubs should never be used for other purposes. Main drain traps should be set perfectly level with regard to their water seals. If the heel of a trap is tipped up, the dip of the trap will not retain sufficient water to form an effective seal; and if the outlet to the trap is tipped up, too much water will be retained in the trap and backed up into the house drain.

Mason traps, full S traps, three-quarter S traps, half S traps, traps without clean-outs or with clean-outs that are made tight with putty or gasket joints, should never be used.

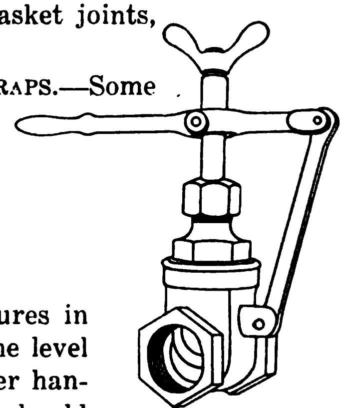


Fig. 16
Quick Closing Gate Valve

SEWER AND TIDE WATER TRAPS.—Some street sewers are so small that water overflows the manholes in the street during excessive rain storms. When a drainage system is connected to such a sewer it should be provided with a tide-water trap, and if any fixtures in the building are located below the level of the street, a quick-closing lever handle gate valve similar to Fig 16 should also be provided to cut off the water in case the tide water valve leaks. When there are no fixtures

connected to the drainage system below the level of the street, the tide water trap should be located where the main house drain enters the building. When, however, the code requires a main drain trap, the tide water trap ought to be located on the street side of the main drain trap. However, when fixtures are located at lower levels than the street surface, they all should discharge into one branch of the house drain, and the tide water trap and quick-closing valve should be placed on that branch. By this arrangement of the valve and tide water trap all fixtures above the street level can be used during overflow periods without overflowing the fixtures at lower levels, as would be the case if the gate valve and tide water trap were placed in the main drain or near the main drain trap. A tide water or backwater trap has already been shown, and in Fig. 17 is shown a combination house-drain and tide-water trap with the side of the trap partly broken away and a cover removed to show the interior.

Fig. 17
Sewer and Tide Water Trap

FLOOR DRAINS.—In breweries, stables, washrooms, bottling establishments, hotel kitchens or other places where sufficient water is poured or splashed on the floor to maintain the seal of a trap, floor drains are permissible. A floor drain is shown in Fig. 18. These fixtures should be provided with heavy brass or iron removable strainers and water seal and, when subject to tide or storm-water floods, a tide water trap. Floor drains should never be used in cellars or basements of buildings unless they are pretty sure to be kept sealed with water; even then they are objectionable, and, if used, should be provided with a tide

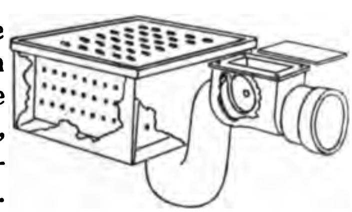


Fig. 18
Floor Drain

water trap to prevent an overflow of sewage should the main drain become stopped up. A deep seal trap is desirable for a floor drain. With a deep seal, the water is not so liable to be lost by evaporation, and the seal destroyed, provided it is re-charged at least once a year. Hot, dry air is seldom found in cellar or basement, and without dry air, little evaporation will take place.

Floor drains with water connections are sometimes required in hospitals, morgues, operating rooms and like places. The valve controling the water is located at the wall at a convenient height and place.

CHAPTER IV

PROPORTIONING THE DRAINAGE SYSTEM

VELOCITY OF FLOW IN DRAINS.—Street sewers and long house sewers should be given such an inclination that the sewage will have a velocity of from 180 to 360 feet per minute. With a velocity much less than 180 feet per minute, the water will fail to carry along the solids held in suspension, and with a greater velocity than 360 feet per minute, the water will run away from the more slowly moving solids. The best velocity for sewage is about 270 feet per minute, and sewer pipes should be run at the proper inclination to produce this velocity. Pipes of small diameter offer greater frictional resistance than those of large diameter, therefore, they must be given a greater fall to produce the required velocity. The proper inclination for drains of any diameter and length to produce a velocity of 270 feet per minute, can be found by the formula:

$f = \frac{l}{10\,d}$, when f = fall in feet, l = length of drain in feet, d = diameter of pipe in inches.

EXAMPLE—What fall should a 6-inch drain, 40 feet long, have to give to the sewage a velocity of 270 feet per minute?

SOLUTION—In this case, $l = 40$ feet, $d = 6$ inches. Therefore,

$$f = \frac{40}{10 \times 6} = .66 \text{ feet or 8 inches fall per 40 feet of drain.}$$

Expressed in the form of a rule, the foregoing formula reads:

Rule—To one foot of fall in the drain, allow a length of ten feet of pipe for each inch in the diameter of the pipe.

From the foregoing formula and rule the grades to be given to different sizes of pipe to produce a velocity of 270 feet per minute have been obtained and are given in Table VIII.

The accepted practice in plumbing is to run the drain pipes at a pitch of not less than ¼ inch to the foot, and most calculations for the proportioning of house drains are based on a fall of ¼ or ½ inch per foot.

SIZE OF HOUSE DRAINS.—A house drain should be large enough to carry off the greatest probable amount of water or sewage that will be discharged into it, without being too large to be self-cleaning. It should never be smaller than the outlet to the largest fixture discharging into the drainage system, and as traps of siphon jet and other improved forms of water closets range in size from $1\frac{3}{4}$ to 3 inches in diameter, a house drain into which a water closet discharges never should be smaller than 3 inches in diameter.

The size of a house drain is determined by the amount of water or sewage it must conduct.

TABLE VIII. Fall for Drains

Diameter of pipe in inches	2	3	4	5	6	7	8	9	10
Length of drain in feet	20	30	40	50	60	70	80	90	100
Total fall to drain in inches	12	12	12	12	12	12	12	12	12
Fall per foot in inches (approximate	3/5	2/5	3/10	1/4	1/5	1/6	1/7	1/8	1/9

In drainage systems that receive the rain water from roof, yard and areas, the amount of impervious surface to be drained and the rate of precipitation, generally determine the size of the pipe. It has been found from measurements that the total amount of sewage passing a given point in the house drain of an ordinary building in a certain period of time is less than one-fortieth the amount of rain water that during excessive rain storms will pass the same point in an equal period of time. In small buildings, therefore, if the house drain is made sufficiently large to carry off all rain water from the projected roof, yard and area surface during excessive and prolonged storms no extra provision need be made for the small amount of sewage that will be discharged into the drain during short periods of excessive precipitation, which seldom exceed five minutes in duration.

In large buildings where the rain water and a large volume of sewage discharge into the same drainage system, the quantity of rain water to be removed should be added to the sewage, and the drain made large enough to carry them both.

The maximum intensity of rainfall, for periods of five, ten and sixty minutes, at weather bureau stations equipped with self-registering gauges, compiled from all available records, can be found in Table IX.

From this table it will be seen that the maximum rate of precipitation varies greatly in different parts of the country, therefore when designing a drainage system for a certain locality to take care of the rain water, the maximum rate of precipitation for five minutes in that locality must be taken into consideration in determining its size. When the rate for any particular neighborhood is unknown, the

***TABLE IX. Intensity of Rainfalls**

Stations 6666	Max. Rate in Feet per Hour	Rate of Downfall per Hour for		
	5 Min.	5 Min.	10 Min.	60 Min.
	Feet	Inches	Inches	Inches
Bismark	.75	9.00	6.00	2.00
St. Paul	.70	8.40	6.00	1.30
New Orleans	.68	8.16	4.86	2.18
Milwaukee	.65	7.80	4.20	1.25
Kansas City	.65	7.80	6.60	2.40
Washington	.63	7.50	5.10	1.78
Jacksonville	.62	7.44	7.08	2.20
Detroit	.60	7.20	6.00	2.15
N. Y. City	.60	7.20	4.92	1.60
Boston	.56	6.72	4.98	1.68
Savannah	.55	6.60	6.00	2.21
Indianapolis	.55	6.60	3.90	1.60
Memphis	.55	6.60	4.80	1.86
Chicago	.55	6.60	5.92	1.60
Galveston	.54	6.48	5.58	2.55
Omaha	.50	6.00	4.80	1.55
Dodge City	.50	6.00	4.20	1.34
Norfolk	.48	5.76	5.46	1.55
Cleveland	.47	5.64	3.66	1.12
Atlanta	.46	5.46	5.46	1.50
Key West	.45	5.40	4.80	2.25
Philadelphia	.45	5.40	4.02	1.50
St. Louis	.40	4.80	3.84	2.25
Cincinnati	.38	4.56	4.20	1.70
Denver	.30	3.60	3.30	1.18
Duluth	.30	3.60	2.40	1.35
Grand Totals	13.8726	166.32	128.18	45.65
Averages	.53	6.40	4.54	1.76

*Report of the Chief of the Weather Bureau, 1896-97. A table of lineal inches in decimal fractions of a lineal foot is given in Appendix 1.

maximum precipitation at the nearest known station may be taken, or a rate of six inches per hour assumed.

The method of calculating the diameter of a drain for any locality is as follows:

Multiply the area in square feet of the surface to be drained by the maximum rate of precipitation in feet per hour in that locality, and divide by 60; this will give the number of cubic feet of water to be removed per minute. Having determined this quantity, the diameter in inches of the pipe required can be found by dividing by 350, extracting the square root and multiplying by 12. This can be expressed by the formula:

$d = 12\sqrt{\frac{a\ p}{21000}}$, in which d = diameter of pipe in inches, a = square feet of area to be drained, p = maximum rate of precipitation in feet per hour, $21000 = 350 \times 60$.

EXAMPLE—What size of drain will be required in Kansas City to drain a roof and other impervious surfaces 40×200 feet, the drain being laid at a grade of ¼ inch to the foot?

SOLUTION—The area *a* to be drained $= 40 \times 200 = 8000$ square feet. The maximum rate of precipitation for Kansas City (see Table IX) is 7.8 inches $= \frac{7.8}{12}$ or .65 foot per hour. Therefore, $d = 12\sqrt{\frac{8000 \times .65}{21000}}$. The square root of $\frac{8000 \times .65}{21000} = .496$, and $12 \times .496 = 5.952$ inches, the diameter of the pipe required to drain 8000 square feet impervious surface in Kansas City. That is practically a 6″ pipe.

Drains are sometimes laid at grades which produce greater or less velocities than 270 feet per minute; when so laid, the capacities of the pipes can be easily ascertained by referring to Table X, which gives the velocity of flow and the number of cubic feet discharged per minute by specified sizes of pipes when laid at different grades. When the area of impervious surface to be drained, the maximum rate of precipitation, and the grade at which drain is to be laid, are known, the quantity of storm water to be removed can be calculated and the size of pipe required to remove it can then be found by this table.

TABLE X. Capacity of Drains Running Full

Velocity in feet per minute as determined by the formula $v = 3{,}000\sqrt{\frac{h}{l} \times d}$ and discharge in cubic feet per minute by the formula $Q = V\ A$ of drains laid at different grades when running full.

In which V = velocity in feet per minute
A = area of pipe in feet
h = head in feet
l = length of the pipe in feet
d = diameter of the pipe in feet

Diam.	2 Inches		2½ Inches		3 Inches		4 Inches		5 Inches		6 Inches	
Fall Ft. in Ft.	Velocity Feet per Minute	Discharge Cubic Feet per Minute	Velocity Feet per Minute	Discharge Cubic Feet per Minute	Velocity Feet per Minute	Discharge Cubic Feet per Minute	Velocity Feet per Minute	Discharge Cubic Feet per Minute	Velocity Feet per Minute	Discharge Cubic Feet per Minute	Velocity Feet per Minute	Discharge Cubic Feet per Minute
1 in 20	273	5.46	297	8.91	335	13.40	390	32.40	432	58.32	480	93.60
1 in 25	246	4.92	273	8.19	300	12.00	345	28.64	387	52.25	450	87.75
1 in 30	220	4.40	249	7.49	270	10.80	312	25.89	351	47.39	390	77.65
1 in 35	204	4.08	228	6.84	250	10.00	288	23.80	324	43.74	360	70.20
1 in 40	192	3.84	216	6.48	237	9.48	272	22.68	306	41.31	330	64.35
1 in 45	180	3.60	201	6.03	222	8.88	255	21.16	288	38.88	315	61.42
1 in 50	174	3.48	192	5.76	210	8.40	243	20.17	272	36.72	300	58.50
1 in 60	153	3.06	174	5.22	190	7.60	216	17.93	245	33.07	270	52.65
1 in 70	144	2.88	162	4.86	177	7.08	204	16.93	229	30.91	252	49.14
1 in 80	135	2.70	150	4.50	165	6.60	198	16.43	210	28.35	214	45.63
1 in 90	129	2.50	144	4.32	156	6.24	180	14.94	201	27.13	222	43.29
1 in 100	120	2.40	135	4.05	150	6.00	170	14.11	192	25.92	210	41.16

Diam.	7 Inches		8 Inches		9 Inches		10 Inches		11 Inches		12 Inches	
Fall Ft. in Ft.	Velocity	Discharge	Velocity	Discharge	Velocity	Discharge	Velocity	Discharge	Velocity	Discharge	Velocity	Discharge
1 in 20	510	135.15	540	189	573	252	620	335	690	455	750	585
1 in 25	480	127.20	480	168	510	224	540	292	570	376	600	468
1 in 30	438	116.07	450	158	471	207	510	275	520	343	540	420
1 in 35	390	103.35	408	143	441	194	456	246	480	316	510	397
1 in 40	363	96.19	390	137	411	180	432	233	450	297	480	374
1 in 45	342	90.63	360	126	390	172	405	218	430	283	450	351
1 in 50	327	86.65	345	120	363	160	390	210	410	270	420	327
1 in 60	288	76.32	309	108	330	145	345	186	360	238	390	304
1 in 70	270	71.55	280	98	306	135	324	175	340	224	360	280
1 in 80	252	66.78	270	94	294	123	309	167	325	214	330	257
1 in 90	240	63.60	258	90	273	120	285	154	300	198	315	245
1 in 100	221	58.50	245	86	258	114	270	146	288	190	300	234

Note—To determine discharge in U. S. gallons multiply cubic feet by 7.5.

EXAMPLE—What size of drain will be required in Kansas City to drain a roof and other impervious surfaces, 50×200 feet, with the drain laid at a grade to produce a velocity of about 270 feet per minute?

SOLUTION—Area to be drained, 10,000 square feet $\times$ maximum rate of precipitation, .65 foot per hour $= 6{,}500$ cubic feet per hour $= 108$ cubic feet per minute. From Table X is found that an 8-inch pipe laid at a grade of 1 to 60 will discharge 108 cubic feet of water per minute, at a velocity of 309 feet per minute. As this rate of flow is well within the permissible range of velocity, an 8-inch pipe may be used if laid at a grade of 1 to 60.

DETERMINING THE SIZE OF HOUSE DRAINS.—A house drain must carry off the greatest amount of storm water likely to be discharged into it, without filling and running the danger of overflowing. If there are no openings in the cellar, however, smaller pipes will carry off the water, for the moment a hydraulic head begins to build up, it will be converted into velocity head, thereby increasing the capacity of the pipe proportionately.

The size of house drains in systems from which rain water is excluded is determined by the number of inmates in the building and the per capita consumption of water. It is obvious that the amount of sewage flowing through a house drain cannot exceed the amount of water used in the building, therefore the house drain need only be large enough to carry off the greatest probable amount of water that will be used at any hour of the day.

The per capita consumption of water in many of the New York State hospitals average at present from 150 to 200 gallons of water daily. In the principal cities throughout the United States the per capita daily consumption of water varies from 36 to 300 gallons, with an average from all the cities of 121 gallons. On the whole, it would seem that a per capita allowance of 100 gallons daily would be sufficient, and at the same time not too much. A study of Table XI shows that in but few cities does the per capita supply fall much below 100 gallons daily, and in those cities that do, all of which are manufacturing cities, it is reasonable to suppose that a large percentage of the people do not have elaborate toilet facilities. In the large cities, on the other hand, where from 150 to 300 gallons of water per capita are used daily, allowance must be made for water

used for fire purposes, street sprinkling, flushing of sewers, etc., which would bring the average consumption of water within buildings for domestic purposes down to about 100 gallons per day. Of this 100 gallons, not over 25 per cent. will be used during any one hour of the day, and that probably will be used at the hour that people arise. It will be used as follows:

Water closets	6 gallons
Preparation of meals, etc.	2 gallons
Laving	2 gallons
Bathing	22 gallons
Scattered	22 gallons
Total	25 gallons

Fifty-five gallons per hour equals .416 of a gallon per minute; therefore, to find the amount of water to be removed by a house drain under the foregoing conditions, multiply the number of inmates the building is designed to accommodate by .416 of a gallon, and the product will be the quantity of water or sewage in U. S. gallons to be removed per minute. The size of pipe required to take care of this amount can then be found in Table X or by the formula:

$d = .234\sqrt[5]{\frac{l q^2}{h}}$, in which d = diameter of pipe in feet, q = cubic feet of sewage delivered per second, h = head in feet, l = length of pipe in feet.

EXAMPLE—What size house drain will be required in a hotel built to accommodate 300 guests and servants, the daily per capita allowance of water being 100 gallons, and the drain to be laid at a grade to produce a velocity of about 270 feet per minute?

SOLUTION—$300 \times .416 = 124.8$ gallons, or $\frac{124.8}{7.5} = 16.6$ cubic feet of sewage per minute to be disposed of. From Table X it is found that a 4-inch pipe, when laid at a grade of 1 to 40, will discharge about 22.68 cubic feet of water per minute.

The size of house drains in buildings is sometimes determined by the following empirical rule:

Rule—Allow one square inch in sectional area of the drain for each two cubic feet, or fifteen U. S. gallons of sewage to be removed per minute.

TABLE XI. Per Capita Consumption of Water

PER CAPITA DAILY WATER CONSUMPTION IN THE FIFTY LARGEST CITIES OF THE UNITED STATES, ARRANGED IN ORDER OF POPULATION.

Cities	Per Capita Consumption in Gallons		Increase or Decrease in Consumption in Ten Years in Gallons	
	1890	1900	Incr.	Decr.
1. New York	79	116	37	....
2. Chicago	140	190	50	....
3. Philadelphia	132	229	97	....
4. Brooklyn	72	...	...	....
5. St. Louis	72	159	87	....
6. Boston	80	143	63	....
7. Baltimore	94	97	3	....
8. San Francisco	61	73	12	....
9. Cincinnati	112	121	7	....
10. Cleveland	103	159	56	....
11. Buffalo	186	233	47	....
12. New Orleans	37	48	11	....
13. Pittsburgh	144	231	87	....
14. Washington	158	185	27	....
15. Detroit	161	146	...	15
16. Milwaukee	110	80	...	30
17. Newark	76	94	18	....
18. Minneapolis	75	93	18	....
19. Jersey City	97	160	63	....
20. Louisville	74	100	26	....
21. Omaha	94	176	82	...
22. Rochester	66	83	17	....
23. St. Paul	60	67	7	....
24. Kansas City	71	62	9	....
25. Providence	48	54	6	....
26. Denver	....	300	...	....
27. Indianapolis	71	79	8	....
28. Allegheny	230	...	...	....
29. Albany	...	191	...	....
30. Columbus	78	230	152	....
31. Syracuse	68	102	34	....
32. Worcester	59	70	11	....
33. Toledo	72	119	37	....
34. Richmond	167	100	...	67
35. New Haven	135	150	15	....
36. Paterson	128	129	1	....
37. Lowell	66	85	19	....
38. Nashville	146	140	...	6
39. Scranton	...	...	...	....
40. Fall River	29	36	7	....
41. Cambridge	64	79	15	....
42. Atlanta	36	84	48	...
43. Memphis	124	125	1	..
44. Wilmington	113	90	...	23
45. Dayton	47	62	15	....
46. Troy	125	183	58	....
47. Grand Rapids	...	156	...	....
48. Reading	75	92	17	...
49. Camden	131	280	149	..
50. Trenton	62	99.9	37	....

EXAMPLE—What size pipe will be required to remove 108 cubic feet of water per minute when the drain is laid at a grade to produce a velocity of about 270 feet per minute?

SOLUTION—$108 \div 2 = 54$ square inches area, and from Table XIV it will be seen that a pipe of about 8¼ inches diameter has the required area. An 8-inch pipe, therefore, would be used.

It is often desirable to know the capacity of drains when running half full. Having the velocity of flow under such condition, the capacity can easily be determined.

The velocity of flow in drains or pipes running partly full can be found by the formula:

$V = \sqrt{\frac{a}{p} 2d}$, in which V = velocity in feet per second, a = area of water in square feet, p = wetted perimeter in feet, 2d = twice the slope in feet per mile.

EXAMPLE—What is the velocity of flow in a 6-inch drain laid at a grade of ¼ inch per foot when running half full?

SOLUTION—There is a 110-foot fall in a mile of drain laid at a grade of ¼ inch per foot. Then

$$V = \sqrt{\frac{.098}{.75} \times 220} = 5.3 \text{ feet per second. Answer.}$$

In Table XII will be found the areas of roof or other quick-run-off surface that can be drained into house drains or leaders of various standard sizes of pipe, laid at grades of ¼ inch and ½ inch to the foot.

TABLE XII. Size of House Drains for Roof Drainage

Diameter of Pipe, Inches	Fall, ¼ inch to the foot	Fall, ½ inch to the foot
3	1,200 square feet	1,500 square feet
4	2,500 " "	3,200 " "
5	4,500 " "	6,000 " "
6	8,000 " "	10,000 " "
7	12,400 " "	15,600 " "
8	18,000 " "	22,500 " "
9	25,000 " "	31,500 " "
10	41,000 " "	59,000 " "
12	69,000 " "	98,000 " "

DRAINAGE OF STORM WATER.—The rainfall on impervious surfaces reaches the sewer as fast as it falls. A different condition obtains, however, when the rain falls on earth.

Then the amount of storm water to be carried off, and the size of drains for the purpose, will depend upon the rate of precipitation per hour; pitch or slope of the area to be drained; area of the drainage surface; and the quantity or proportion of the rainfall that will reach the sewer in a given time. According to Table IX, the greatest rate of downpour is 2.55 inches per hour, and the average is 1.75 inches per hour.

TABLE XIII. Carrying Capacity of Sewer Pipe

Size of Pipe, Inches	Gallons Discharged per Minute							
	1-Inch Fall per 100 Feet	2-Inch Fall per 100 Feet	3-Inch Fall per 100 Feet	6-Inch Fall per 100 Feet	9-Inch Fall per 100 Feet	1-Foot Fall per 100 Feet	2-Foot Fall per 100 Feet	3-Foot Fall per 100 Feet
3	9	12	15	22	27	31	44	54
4	20	28	35	50	62	71	101	124
6	63	89	111	156	194	224	317	389
8	140	198	246	348	432	499	706	864
9	196	277	339	480	595	687	971	1180
10	261	369	457	648	803	928	1310	1610
12	432	612	758	1070	1330	1530	2170	2660
15	800	1130	1400	1980	2450	2830	4010	4910
18	1320	1860	2310	3260	4040	4660	6590	8080
20	1720	2500	3060	4330	5305	6130	8660	10610
24	2910	4110	5035	7191	8810	10270	14520	17790
27	4020	5680	6960	9840	12050	13920	19680	24110
30	5380	7618	9320	13180	16140	18640	26350	32280
33	6950	9840	12050	17040	20865	24090	34070	41730
36	8800	12450	15210	21565	26410	30500	43130	52820

Experience shows that, owing to various causes, such as evaporation, porosity of soil, obstructions, and absorption, only from 50% to 75% of the rainfall will reach the drain within an hour. Severe storms are of brief duration, so if provision is made to carry off the hourly rainfall, that will be sufficient. Where the rainfall exceeds 2 inches per hour, the rate of precipitation for that period can be multiplied by the area to be drained, and 50% to 75% of that amount allowed to reach the sewer. Ordinarily, however, an allow-

ance of 1 inch per hour will be sufficient, assuming that the entire 1 inch of rainfall reaches the sewer in an hour.

One inch rainfall per hour is equal to 3,630 cubic feet, or 27,225 gallons of water to be removed per hour from each acre of surface.

When the area to be drained, and the fall of sewer per hundred feet are known, the size of pipe required can be found in Table XIII, which gives the capacities of large sewer pipes when running full.

CHAPTER V
DETAILS OF THE HOUSE DRAIN

Fresh Air Inlets

DEFINITION.—A fresh air inlet is a pipe connected to the main house drain inside of the main drain trap, and extending to a point outside of the building where it is open to the atmosphere. Its object is to admit fresh air to circulate through the drainage system to keep the air within comparatively pure; also to act as a relief pipe to prevent compression of air within the system when a heavy flush of water, in descending, fills the pipe full bore, or when a strong gust of wind blows down the vent stacks from above the roof. If a passage for the escape of air were not provided for such occasions the compression of air in the drain pipes would force drain air through the seal of some of the traps. It is quite evident from the function of a fresh air inlet that any form of check valve or inlet fitting that prevents air escaping from the mouth of the pipe during heavy discharges or "blow backs" should not be used.

CONNECTION TO HOUSE DRAIN.—The fresh air inlet should connect to the house drain by means of a T branch. It should never connect to the clean-out opening of a trap. In cold climates, such as the northern part of the United States and Canada, the fresh air inlet should be connected to the main drain from 5 to 15 feet inside of the main drain trap. If connected to the main drain near the trap the rapid circulation of cold air through the system will, in winter weather, freeze the water in the trap.

LOCATION OF OUTLET.—The mouth of a fresh air inlet should be located at least 12 feet from all windows, doors, ventilator shafts or flues communicating with a building, and the end should be so protected that it cannot be obstructed by children or choked with dirt, water, snow, leaves or ice. In some of the large cities the fresh air inlet opens into the side of a box located at the curb, and is pro-

tected by a removable metal grating. When so located, the bottom of the box should extend at least 18 inches below the bottom of the pipe to prevent the mouth of the fresh air inlet becoming choked with dirt. The principal objections to this form of inlet are, first, the box is seldom, if ever, cleaned, and in the course of time fills up with dirt; second, during winter weather the grating becomes completely choked with snow and ice.

In detached houses the fresh air inlet generally is extended 15 or 20 feet away from the building, and the end protected with a return bend that opens facing the ground. When this form of inlet is used, it is good practice to locate the inlet in a clump of bushes or some other place equally inaccessible to children.

When sufficient space can be found in the foundation wall of a building, near the main drain trap and far enough from all openings to the house, the fresh air inlet can be located there, and the inlet protected by a metal strainer *a*, Fig. 19, secured to the stone work. This makes a very superior form of inlet.

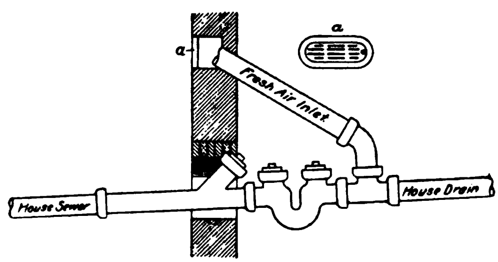


Fig. 19
Fresh Air Inlet

In fresh air inlet grates the openings should equal in area the size of the fresh air inlet pipe, and the size of the opening in the grate should be not less than one-half inch in their least dimension.

SIZE OF FRESH AIR INLETS.—Fresh air inlets should be the full size of the house drain for all sizes of drains up to 4 inches in diameter. A 4-inch fresh air inlet is large enough for a house drain 8 inches in diameter. For larger house drains the fresh air inlet may be one-half the diameter of the house drain.

It might be well to emphasize here that a fresh air inlet is absolutely unnecessary unless there is a main drain trap in the house drain; and, as the main drain trap is

objectionable, it should be used only in those cases where antiquated plumbing codes require it. The fresh air inlet, therefore, is to be used not because it is good or necessary, but because the law demands it.

Rain Leaders

KINDS OF LEADERS.—Rain leaders may be divided into inside leaders and outside leaders. *Inside Leaders* are located within some parts of the building secure from frost, and are installed by the plumber. They are made of cast iron or wrought iron pipe and put together perfectly gas and water-tight. *Outside Leaders* are usually made of sheet metal with loose slip joints, and from a point about 5 feet above grade, are installed by the sheet metal worker. Up to a point a few feet above grade outside leaders should be of cast iron or wrought iron pipe to withstand the rough usage they are likely to receive.

TRAPPING OF LEADERS.—Rain leaders usually are trapped with a running trap placed in the horizontal part of the leader just inside the cellar wall, secure from frost. When inside leaders are used, however, or when outside leaders are made perfectly gas and water-tight and do not open near windows, doors, flues or ventilator shafts, a better practice is to omit the trap and use the leader also for a vent pipe.

ROOF CONNECTIONS.—Inside rain leaders should have special roof boxes properly flashed to the roof, and should preferably be connected to the roof gutter by means of a lead, brass or copper offset, or a short length of brass or copper pipe of about No. 20 Stub's gauge corrugated to make it flexible and collapsible, as shown in Fig. 20, to take up the creeping of the line due to expansion and contraction. Lead pipe may likewise be used for this purpose if it is made flexible and collapsible. If of lead, the pipe should weigh not less than 6 pounds per lineal foot for 4-inch pipe; 8 pounds for 5-inch pipe, and 10 pounds for 6-inch pipe. The flexible fitting must be securely soldered to the gutter, and flanged to the under side so that any

creeping of the line will not affect the joint at the roof. The other end of the fitting should be calked or screwed into the iron pipe by means of solder nipples or brass ferrules solder wiped to the lead pipe or made part of the brass pipe. The Holt roof connection, also the Josam are good types of leader heads that have proven serviceable in use. Roofs that are surrounded with parapet walls should have scuppers or overflows built in them through which water can escape in case the leader inlet is obstructed with ice.

Inside leaders should be so located and installed that in case the inlet is clogged with ice or otherwise obstructed the rain water can overflow through a scupper to the ground or to another roof surface. If, for instance, a leader were located at the center of a square building having a flat roof, and the inlet became clogged, the water would be retained on the roof forming a pool of dangerous weight. In industrial buildings of the saw-tooth type, it is bad practice to run horizontal leader mains under the roof, taking branches up to the several gutters. In this location the pipe becomes heated to the temperature of the hottest part of the room, then quickly chilled from a cold rain. Lead-calked joints are liable to work loose under such temperature changes, so if the leaders must be installed that way, they had better be of screw pipe.

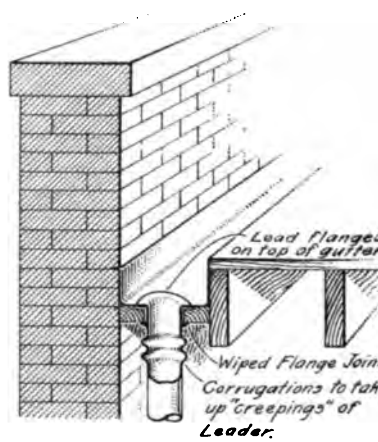


Fig. 20
Flexible Connection for Roof Gutter

Outside leaders should be provided on the top with a service box, into which the roof water can discharge. This service box should be set low enough so in case the leader becomes stopped with ice, the water can overflow the box

without backing up on the roof. The principal objection to outside leaders is that they freeze and burst. In cold climates outside leaders are a source of worry and expense that can be avoided by the additional first cost of inside leaders. The bursting of outside leaders from frost can be reduced to the minimum by using corrugated pipe in place of cylindrical; then, when the water expands upon freezing, the corrugations yield to the pressure without the pipes bursting. Cast iron pipe with lead calked joints never should be used for soil waste or leader pipes where exposed to frost. Even though the pipe is usually empty, the oakum used in calking the joints becomes wet from the water flowing through the pipe, which, upon freezing, forces the lead out of the joints, causing leaks.

SIZE OF LEADERS.—The Barrett Company, from their extensive experience in roofing, advances the following two paragraphs and Table XV:

For large roof areas (more than 4,000 square feet) it is considered the best practice to drain to different points, using smaller leaders, rather than to one outlet of large size, although in some cases the arrangement of leader-lines makes the latter arrangement compulsory.

A reliable table not always being available, an easy and reliable formula to use is to allow: for roofs covered with gravel or slag with an incline not exceeding one-quarter of an inch per foot, 300 square feet of roof surface to each square inch of leader opening; for roofs of greater incline, or saw-tooth roof construction, 250 square feet roof surface to each square inch of leader opening; for metal, tile, brick, slate or similar roofs of any incline, 200 square feet of roof surface to each square inch of leader opening. Table XV can be depended upon in estimating roof drainage, it being based on the heaviest storm conditions recorded.

Rule—Allow 1 square inch in sectional area of the leader for each 250 square feet of saw-tooth roof surface.

EXAMPLE—What size of leader will be required to drain a roof 75 feet long by 50 feet wide?

SOLUTION— $\frac{75 \times 50}{250} = 15$ square inches, and from Table XIV it is found that a 4½-inch pipe has an area slightly greater than 15 inches.

The area in square inches and in square feet of pipes from 2 inches to 12 inches in diameter can be found in Table XIV.

TABLE XIV. Diameter and Areas of Pipes

Diameter of pipes in inches.......	2	2½	3	4	4½	5	6	7	8	9	10	12
Areas of pipes in sq. inches	3.14	4.9	7.06	12.57	15.9	19.63	28.27	38.48	50.25	63.61	78.54	113.1
Areas of pipes in sq. feet...	.02	.03	.04	.083	.11	.135	.195	.265	.35	.44	.54	.785

EXPANSION AND CONTRACTION OF LEADERS.—The variations in length of leaders due to change in temperature has always been more or less of a problem, but it becomes a serious one to take care of the expansion and contraction in tall office buildings. Take a building 400 feet tall, for instance. In such a building while the pipes are at a uniform temperature of 70 degrees Fahrenheit or more, a cold rain or snow comes on, and water at a temperature of about 35 degrees Fahrenheit chills the pipe in a few minutes through a range of at least 35 degrees. If the change of

TABLE XV. Size of Leaders

	SIZE OF LEADER, INCHES					
	2½	3	4	5	6	8
Roofs covered with gravel, slag or other similar material with incline ¼″ to 1 ft....	1800	1800 to 2200	2200 to 3600	3600 to 5600	5600 to 8000	8000 to 14000
Same with incline ½″ to 1 ft. or more and saw-tooth roofs	1200	1200 to 1700	1700 to 3100	3100 to 4900	4900 to 7000	7000 to 12000
Metal, tile brick, slate or similar roofs of any incline..........	1000	1000 to 1400	1400 to 2500	2500 to 3900	3900 to 5600	5600 to 10000

temperature came on gradually so the molecules of the rain leaders could have time to adjust themselves slowly to the varying length, the destructive force would not be so serious; but, the sudden changes coupled with the numerous changes which take place during the year, requires that special precautions be taken to avoid damage. In a building 400 feet tall with this variation of temperature in a cast iron rain leader, it would contract or expand approximately ½ inch, while a wrought pipe would change even more in length. To compensate for this variation in length, collapsible or flexible fittings or expansion joints of some kind should be used.

Yard and Area Drains

Yard and area drains in a sense are rain leaders. Their object is to remove storm water from yard and area surfaces; therefore, what has been written about the size and materials of rain leaders will apply equally to yard and area drains.

YARD AND AREA CATCH BASINS.—A yard or area drain is shown in Fig. 21. This is simply a plain cast-iron receptacle with removable perforated cover. It is located in the yard or area to be drained, so the rain water can drain into it and pass thence through a pipe connection to the main house drain. Catch basins should be so constructed that all water will drain out of them immediately, and the area of perforations in the covers should be at least equal to twice the area of the drain pipe.

TRAPPING YARD AND AREA DRAINS.—Yard and area drains should be trapped with running traps located inside of the foundation walls where they are accessible and safe from frost. When convenient to do so they should connect to a rain leader. If the rain leader is trapped the yard or area drain should connect to it on the yard side of the trap, and the leader trap will then serve for both. The objects of connecting a yard or area drain to a rain leader are to insure a permanent seal to the trap, or in the event of the seal failing, to provide a draft, down through the area drain and up through the rain leader.

While it is better not to trap rain leaders when they are gas and water tight, and do not open near windows, doors, or other inlets to the buildings, it is never advisable to install yard or area drains unless they are well trapped with a good running trap, preferably of deep seal, and placed where the water will not likely be evaporated from the seal. Yard and area drains are generally placed in such locations that drain air would blow through them in case they were untrapped, and the drain air would either be inhaled by those working or otherwise occupied in the yard, or the drain air might find its way into the building through a near-by door or window. Yard and area drains should never be placed in a position or location where they cannot be supplied with water at frequent intervals whenever it rains.

GASOLINE AND OIL SEPARATORS.—Closely allied with yard and area drains are garage drains. Too great care cannot be exercised to keep from entering the main sewers the gasoline drippings from motor cars, and the oils used in cleaning and lubricating. Disastrous explosions, tearing up the street for miles, and doing millions of dollars worth of damage have been caused by the ignition of an explosive mixture of gasoline vapor and air. Illuminating gas is another source of danger when it escapes from the gas mains and enters the street sewers.

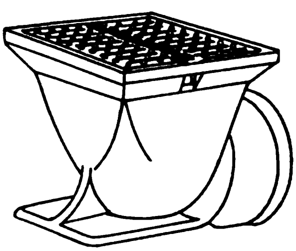


Fig. 21
Yard or Area Drain

Oil separators should be installed in public and other large garages, to trap out the oil and gasoline. They are nothing more or less than large grease traps, which are connected to a system of piping independent of the main system. They have their own main-drain trap and fresh-air inlet; a 2-inch vent pipe from tank to roof; a system of piping which takes the waste from all floor drains and carriage washes where oils and gasoline are used; and a main vent stack of the full size of the oil system drain, extending through the roof.

CHAPTER VI
SIPHONS AND SIPHONAGE

DESCRIPTION OF SIPHON AND SIPHONAGE.—There is no apparatus or no force having so many uses and functions in plumbing practice as the siphon. Most of the apparatus used in plumbing are operated by means of siphons; on the other hand, siphonage causes more trouble than anything else. It is siphonage which destroys the seals of traps when not properly ventilated, and the same invisible force which causes range boilers to collapse.

A siphon can be seen in Fig. 22, which shows one of the simplest forms. It is nothing more or less than a bent tube or pipe, made in the form of a letter U, but having legs of unequal length. That is the prime characteristic of a siphon of any kind, to have legs of unequal length, for if both legs were of the same length it would not be a siphon, and would not operate as one.

The operation of the siphon is simple. If the short leg of the empty tube were immersed in a pail of water, as shown in the illustration, water would rise in the short leg to the level of the water in the pail, and that is all. The water would not run out of the vessel through the bent tube. If before placing the short leg of the siphon in the water, however, the tube be filled with water, then as soon as the tube is in the position shown in the illustration water will commence to flow through it and will continue to flow until the water in the bucket has been lowered to the mouth of the short leg. Air will then pass into the pipe and break the siphonage. It will be observed that in flowing from the pail through the siphon, the water is carried some distance above the level of the water in the pail. That is another feature of the siphon to be kept in mind, for it will raise water to a level higher than the source before discharging it, but will never discharge the water at a higher level than the source. On the contrary, the long leg of the siphon must be turned down, and the outlet must be at a lower level

than the surface of the water in the pail, or the siphon will not work.

The pressure of the atmosphere is bearing down on the surface of the water in the pail with an intensity of 14.7 pounds to the square inch, assuming that it is at sea level. This pressure is transmitted to the mouth of the short leg of the siphon, so that there is an upward pressure of 14.7 pounds to the square inch tending to drive the water up into the short leg. But the pressure is bearing upward at the mouth of the long leg with equal intensity, so that the air pressure at the inlet just balances or offsets that at the outlet, thereby leaving the water in the siphon as though not acted upon by the pressure of the air at all.

Whatever motive force there is, then, must be due to the difference in length of the two columns of water, one in the short up leg immersed in the pail of water and the other the long down leg outside the pail. If we assume, therefore, that there is a distance of one foot between the surface of water in the pail and the top of the siphon, and that the long leg of the siphon is five feet in length, then one foot in length of the long leg would offset or counterbalance the foot of lift in the short leg, leaving a difference at the beginning of the operation between the long leg and the short leg of a column of water four feet high. This unequal weight of water would, of course, cause the four feet of water to run out of the long leg; but that would tend to create a vacuum in the down leg at a point level with the water in the pail. However, as Nature abhors a vacuum, instead of one being formed, the pressure of air on the surface of the water in the pail forces more water in to fill the space, and so a continuous flow is established.

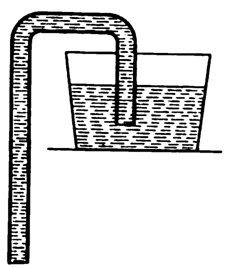


Fig. 22
Simple Siphon

EFFECT OF AIR LEAKAGE ON A SIPHON.—To operate successfully, a siphon must be perfectly tight. Even a little pinhole at the top of the siphon will let in air enough to break the continuity of flow and stop the siphonage. Water,

and nothing but water, or the liquid that is being siphoned, must be in the siphon. In large, permanent siphons, through which water is flowing continuously, there is a tendency for air to accumulate at the top of the siphon and break its action. This air comes from the water itself. Water has a certain capacity for air, and at atmospheric pressure and ordinary temperature will absorb about 4 per cent. Increasing the pressure or lowering the temperature will increase its capacity to absorb air, while decreasing the pressure or increasing the temperature will lower its capacity for air. The water at the top of a long siphon is at an appreciably lower pressure than at the intake, and chances are the temperature is slightly raised, too, particularly if the pipe is exposed to the sun.

The result would be that the capacity of the water to absorb air or hold it in solution would be lowered, and some would be liberated as free air to collect at the top of the siphon. This is a trouble frequently encountered in hilly or mountainous countries where a siphon line is used to draw water from a lake or stream over a low hill into a valley on the other side. Air keeps accumulating at the top of the siphon and has to be let out occasionally or the siphonage will be broken and the siphon will have to be started all over again. In pipe lines of such description air vents are provided at the highest points, so that the air can be permitted to escape without at the same time breaking the siphon.

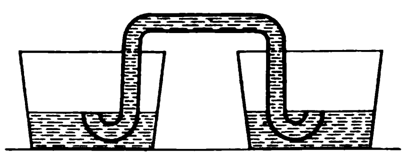


Fig. 23
Siphon Maintaining Level of Liquid in Two Vessels

SIPHON FOR EQUALIZING WATER LEVELS.—Another form of siphon is shown in Fig. 23. This form of apparatus, instead of siphoning water from one level to a lower one, transfers the water from one vessel to another one at the same elevation, and maintains the water in both vessels at a common level. The siphon is turned up at both ends where it is immersed in the water, to prevent air from

entering and displacing the water, and the siphon, of course, at all times while in use is full of water, or of the liquid to be transferred. If water is now poured into one of these vessels, it will immediately commence to flow through the siphon into the other vessel, and will continue to flow so long as there is a difference in level between the surfaces of the water in the two vessels. This simple form of siphon proves more conclusively than any other form that the flow is caused by a difference in head of water in the two legs, and that back of it all it is the pressure of the atmosphere which causes the siphon to operate. In a perfect vacuum there would be no such thing as siphonage, because there would be no pressure to force the liquid up into the short leg of the siphon.

As the operation of a siphon is dependent upon the pressure of the atmosphere, it is in some respects like the operation of a pump which owes its action to the exhausting of air from the suction pipe, which is then filled with water by the pressure on the water in the well or other source of supply. Like the pump suction, too, there is a limit to the height that water can be raised by siphonage. At sea level the theoretical height that a siphon can raise cold water is 33.95 feet. As a matter of fact, however, in practice it is doubtful if the water could be raised a greater height than 25 feet, and even that would be an extreme lift. Twenty to twenty-two feet would probably be more nearly the lift of a siphon under usual working conditions.

APPLICATION OF SIPHONAGE TO A FIXTURE TRAP.—In Fig. 24 is shown another form of siphon. This does not differ so much from the first one shown, outside of the fact that instead of lifting the water over the top edge of the vessel it takes it out of the side near the bottom, then turns upward to near the top of the vessel, or higher according to the use to which it is to be put, then forms the well-known U-shaped tube which is the distinguishing feature of the common siphon. The resemblance here to a common siphon trap is shown by means of dotted lines. If instead of the vessel of water the part of the tube shown by dotted lines be supplied, we have a trap such as is used under

plumbing fixtures, and the reason it can be siphoned becomes apparent. When the long leg of the siphon becomes filled with water, it will draw the water out of the dip of the trap until the water line is lowered enough to allow air to flow in and break the siphonage, just as it would if instead of a trap, it were a common vessel that the siphon was attached to.

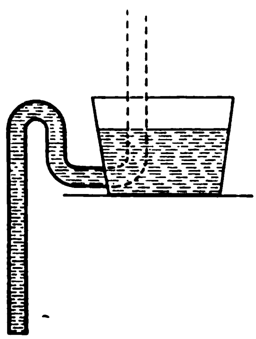


Fig. 24
Half S Siphon

The principle of ventilation of fixture traps can be clearly understood by referring to Fig. 25. As was previously pointed out, the least little pin hole at the crown of the siphon, or in the long leg of the siphon, above the bottom of the short leg, will permit enough air to enter the pipe to destroy the siphonic action. That fact is taken advantage of to protect traps from being siphoned in plumbing systems. If, for instance, a pet-cock were placed in the crown of a trap, as shown in the illustration, when the cock is closed the trap would form a true siphon; but the moment it is opened, or a hole left in the top of the trap, siphonic action would be broken and the water seal in the trap would remain intact. So far as preventing the loss of seal of the trap is concerned, then, a short piece of pipe a few inches long soldered to the crown of the trap and open at the top is all that would be required. But with a short pipe like that there would be two unsanitary conditions. In the first place, in case of a stoppage water might rise high enough in the system to overflow from the pipe and flood the building. In the second place, it would defeat the very object aimed to prevent. Almost everything in the trapping of fixtures is a compromise—not the ideal. Fixtures would be better off connected up with a straight piece of pipe, only in that case the sewer gas would flow through

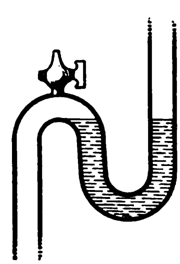


Fig. 25
Vent for Siphon

into the building. As a remedy, the trap is used as a compromise. But the trap itself is liable to lose its seal by siphonage if provision is not made to protect it. If, then, we compromise again by connecting only a short piece of pipe open at the end, siphonage will be prevented, but the vent pipe will be open to the free discharge of sewer gas, the very thing the trap is intended to prevent. The only way to solve the problem is to extend the vent pipe from each trap up to and through the roof, and there let it open to the atmosphere. But again we compromise. If each individual vent pipe from a trap were extended through the roof, the cost would be excessive and the building would be cut up with pipes more than is necessary. To keep down the cost, then, and protect the building, a main vent stock is run up through the roof, and all the vent branches from near-by traps are connected to this stack. The ventilating of traps it will be seen, then, is a simple thing. Any number of branch vents can be connected to one stack, the only requirement being that the stack be proportioned to the number of branch vents; and, no mistake can be made in running the branch vents to the stack, for all that is necessary is to see that the branches are large enough, all kept high enough, and have a fall from the vent stack towards the fixture traps so any water finding its way in will find its way to the waste pipe and not remain in the vent pipe to form a trap. Viewed in this light the system of vents and re-vents becomes simple, for it is merely running a main stack like the trunk of a tree, and taking off branches of the required size at the right floors, like the limbs of the tree.

A different type of siphon used for a flushing device in a water closet tank is illustrated in Fig. 26. This siphon is formed by means of a cup-shaped member inverted over a straight piece of pipe. The space between the cup-shaped piece and the straight pipe forms the up leg of the siphon, or what is commonly called the short leg, while the long leg is represented by the flush pipe.

The operation of this siphon is as follows: The tank and space between the inner tube and outer cup-shaped

casing of the siphon are filled with water to the level shown in the illustration, but the inner tube of the siphon and the flush pipe are empty. When the chain is now pulled, the valve *a* is raised from its seat, and water flows in, filling the flush pipe. The long leg of the siphon is now charged, the chain is released and the valve settles back on its seat. But the flow of water down the flush pipe now tends to create a vacuum in the space marked *b*, so pressure of the atmosphere on the face of the water forces water over into the tube, and the siphon continues until the tank is empty. Usually a small hole near the bottom of the outer casing is provided to gradually break the siphonic action when the

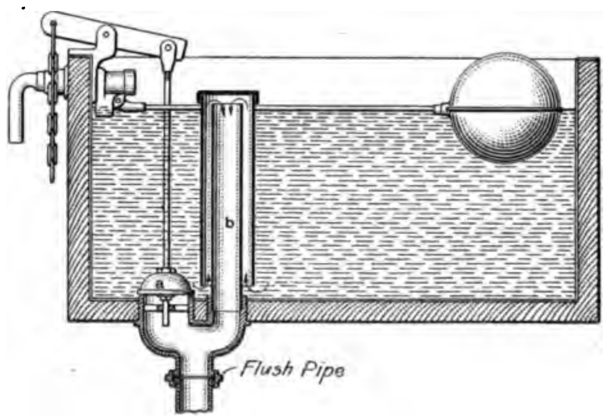


Fig. 26
Siphon Applied to Closet Tank

water lowers enough to uncover the hole and allow air to enter.

APPLICATION OF SIPHONS TO CLOSETS.—Most of the closets made today, and all of the better types, including siphon-jet closets, siphon-action hoppers and reverse-trap siphon action closets, are simply siphons and operated by siphonage. The principle of siphonic action applied to closets is shown in Fig. 27. The short leg of the siphon is shown at *a* and extends from the trap inlet to the crown of the bend, while the descending leg *b* forms the long leg of the siphon. It will be noticed that the outlet passage instead of being straight is more or less tortuous. This is to

dash the water from one side to the other in order to make the minimum amount of water fill the bore or rarefy the air and start siphonic action. In the siphon jet the operation of the siphon is aided by a jet of water *c*, which, shooting up the short leg of the siphon, has a heaving effect which quickly puts over enough water to start the siphon in operation. In siphon-action closets the ordinary flow of water from the flushing rims, by raising the water level, causes an overflow and starts the siphon.

Generally speaking, the siphon is of great benefit in plumbing, although there are conditions under which it becomes an agency of destruction. Range boilers, for instance, are sometimes collapsed when the water from within is siphoned out. Suppose, for example, a 40 gallon range boiler is connected up on the first floor of a building on the side of a hill. The supply pipe from the water main is then the long leg of the siphon, and the boiler tube inside of the boiler the short leg of the siphon. Now, if the water be shut off from the street main, and the pipe emptied, the siphon is set in operation, the boiler is partly emptied, and unless air gains entrance some how to equalize the pressure on both sides of the boiler, the tank will collapse.

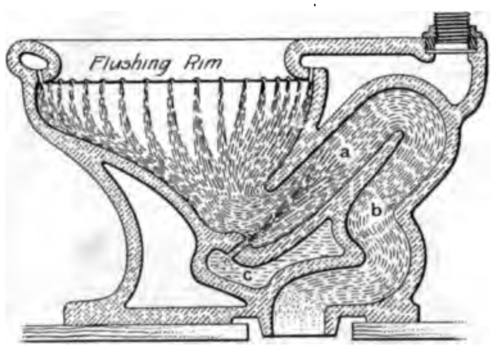


Fig. 27
Siphon Applied to Closet

An ordinary range boiler of 40 gallons capacity is five feet high by 14 inches in diameter. If we do not count the heads but just include the sides of the cylinder, we will find that there are about 18 square feet of surface to the tank. Each square foot of surface contains 144 square inches, or the boiler contains 2592 square inches all told. On each square inch of surface the atmosphere is bearing down with

a pressure of 14.7 pounds per square inch; and 2592 square inches times 14.7 pounds per square inch equals 38,102 pounds, or over 19 tons pressure. This pressure must be equalized by a similar pressure inside the boiler, or the boiler will collapse from the weight of the atmosphere, as frequently happens when boilers which are not properly protected have their contents partly siphoned out by shutting off the supply of water, then opening a faucet at a much lower level.

The siphon, then, is a most useful contrivance in both plumbing practice and engineering work. It is only in exceptional cases that it operates against instead of in favor of useful effort. It is used for conducting water over low ranges of hills into valleys where the water will be needed. It is used to operate most of the closets used in present-day practice. It operates many of the closet tanks now in use, and is the principle upon which many automatic apparatus operate; while on the other hand, in only two cases is it of detriment to the plumber, and in those two cases the possibility of damage can be avoided, if the plumber is familiar with the siphon, with siphonage, their uses and limitations. Those two cases are the possibility of traps siphoning when not properly installed, and the companion possibility of range boilers collapsing if not protected against the formation of a partial vacuum.

CHAPTER VII
SOIL, WASTE AND VENT SYSTEMS

Stacks and Branches

DEFINITIONS.—Soil stacks are those pipes which receive the discharge from water closets and urinals, although they may also receive the discharge from other fixtures. They connect with the house drain in the cellar or basement, and extend to a suitable point above the roof.

Soil pipes are the branches which connect closets or urinals with soil stacks.

Waste stacks receive the discharge from fixtures other than water closets or urinals. They also connect with the house drain and extend to a suitable point above the roof.

Waste pipes are those which connect any fixtures other than water closets or urinals with either a waste stack or a soil stack.

A vent stack is a special ventilating pipe that connects with a soil or waste stack below the lowest fixture and extends to a point above the highest fixture, where it may again connect with the stack or extend separately through the roof. No soil or waste matter discharges into this pipe. Its function is to provide a supply of air to the outlets of fixture traps, to prevent the water seal being broken either by siphonage or by back pressure. Those portions of soil and waste stacks above the highest fixtures may be considered as vent stacks.

A vent pipe is a short branch extending from the vent stack to the trap it ventilates.

TWO-PIPE SYSTEM OF PLUMBING.—There are three systems of roughing in for stacks and branches in use at the present time; they are known as the *two-pipe system*, the *single pipe system* and the *loop* or *continuous vent system*. In the two-pipe system, siphon traps are used, and their seals are protected from siphonage by a system of vent pipes. The principles of installation of the two-pipe system are shown in Fig. 28. In this system a vent stack

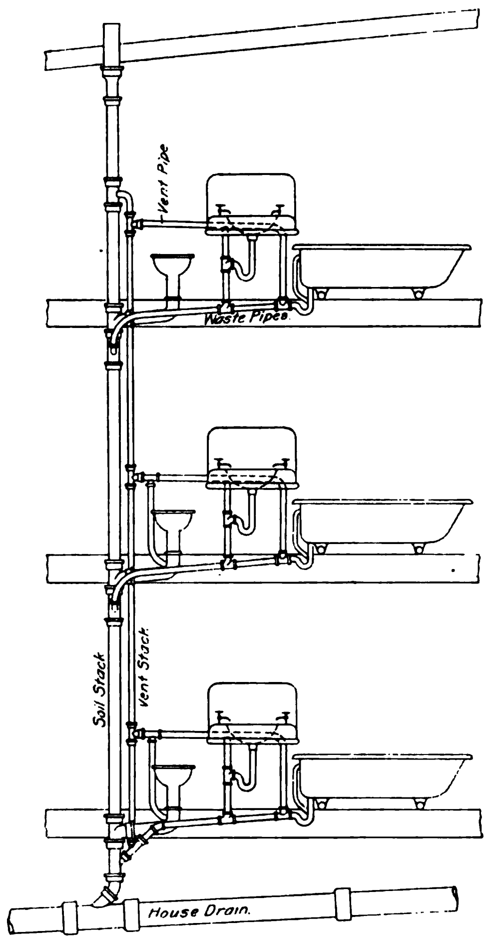


Fig. 28
Two-Pipe System of Plumbing

intersects the soil stack at an angle of 45 degrees at a point below where the lowest fixture discharges into the soil stack. The object of connecting the soil and vent stacks together at this point is to provide an outlet from the vent stack into the soil stack for rust scales or other foreign matter which might enter it. In the illustration the vent stack rejoins the soil stack at a point above the level of the highest fixture discharging into it. This connection is made only for economic reasons, however. The vent stack may be extended separately through the roof, and in buildings over six stories in height it is better to do so. On stacks three or more stories in height the waste pipe from the wash basin and bath tub on the first floor is generally connected to the heel of the vent stack to wash out any foreign matter that might lodge there. This provision, however, is of more importance in wrought iron systems than in cast iron systems, owing to the greater possibility of wrought iron stacks being stopped at this point by rust scales. Connections to vent stacks are made at a point above the level of the outlet from the highest fixture in the group; and all the vent pipes drain toward their respective traps so that water of condensation or sewage that backs up in the vent pipes, during stoppage of the waste pipe, will drain out again when the waste pipe is clear. Should the connection to the vent stack be made at a level lower than the outlet from the fixtures, the waste pipe might become stopped up and the fixture would waste through the vent pipe without the stoppage becoming known. The principles and practice of the two-pipe system are fully explained in the foregoing description. More fixtures may be connected to a stack or more stacks may be installed in a building, but they are only a multiplication of units of which this illustration is an example.

ONE-PIPE SYSTEM OF PLUMBING.—In Fig. 29 is shown, diagramatically, the one-pipe system of plumbing. This illustration should be compared with the illustration of a two-pipe system, to see wherein they differ. In the one-pipe system non-siphon traps are used without vent pipes. This method of piping reduces the cost of roughing to almost one-half the cost of the two-pipe system, and necessitates

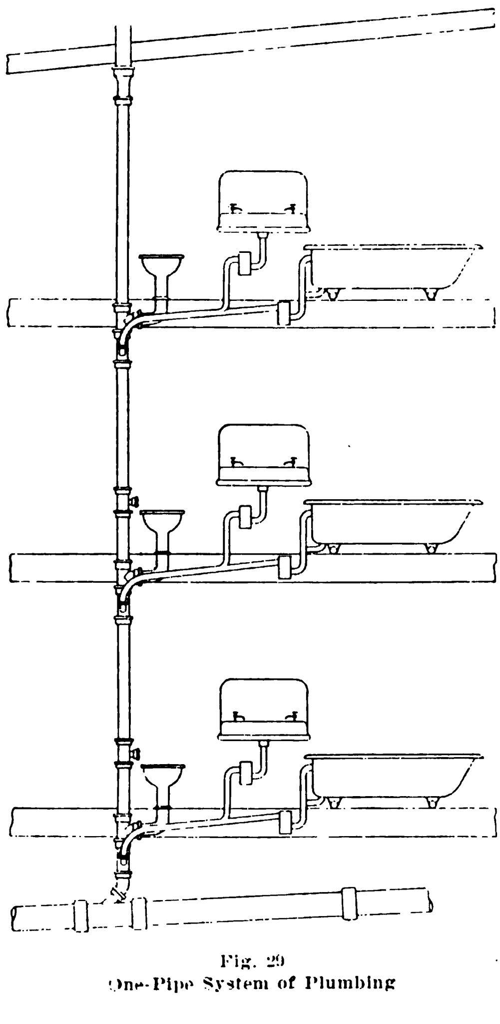


Fig. 29
One-Pipe System of Plumbing

less cutting of walls and floors. For some purposes, for instance, where clear water only will be used, and in small installations the one-pipe system, with approved non-siphon traps, may be equal to the two-pipe system. It is open, however, to the objection that a slight gurgling noise might be heard in the waste pipes due to siphonic action of the trap when a fixture is flushed. The illustration shows the waste from the lavatory discharging into the bath-tub waste. A better way is to connect the lavatories separately to the stacks in the fittings shown at the two lower floors. When that is done, non-siphon traps need not be used. Ordinary siphon traps will answer as well. The one-pipe system of plumbing can often be used without resorting to non-siphon or refill traps. Ordinary siphon traps, which are not only the best, but generally speaking the cheapest, being used. Some examples of the one-pipe system of plumbing with siphon traps are given in a later chapter.

LOOP OR CONTINUOUS VENT SYSTEM.—The loop or continuous vent system of plumbing is shown, diagramatically, in Fig. 30. The fixtures instead of being separately vented as in the case of the two-pipe system of plumbing, are simply connected to a horizontal soil pipe with a continuous loop extending to the vent stack and connecting to it above the top of the highest fixtures in the group. This system is more suitable for water closets than for other fixtures, for the reason that the types of closets now used are siphon acting, with refill provision made, so that after the closets are flushed the traps fill automatically. With small fixtures on the other hand, to extend their waste pipes down to the horizontal soil pipe would constitute long legs with which to siphon all water out of the traps. A battery of lavatories, however, can be connected up this way to a waste pipe directly back of them, by means of half S traps.

It will be observed that the horizontal pipe is perfectly rigid, there being no possibility of it yielding when the floor joists dry out and shrink. There ought, therefore, to be some provision made to take up the shrinkage of the joists, otherwise the closets will be held above the floor a distance equal to the shrinkage, or some part of the system, probably the

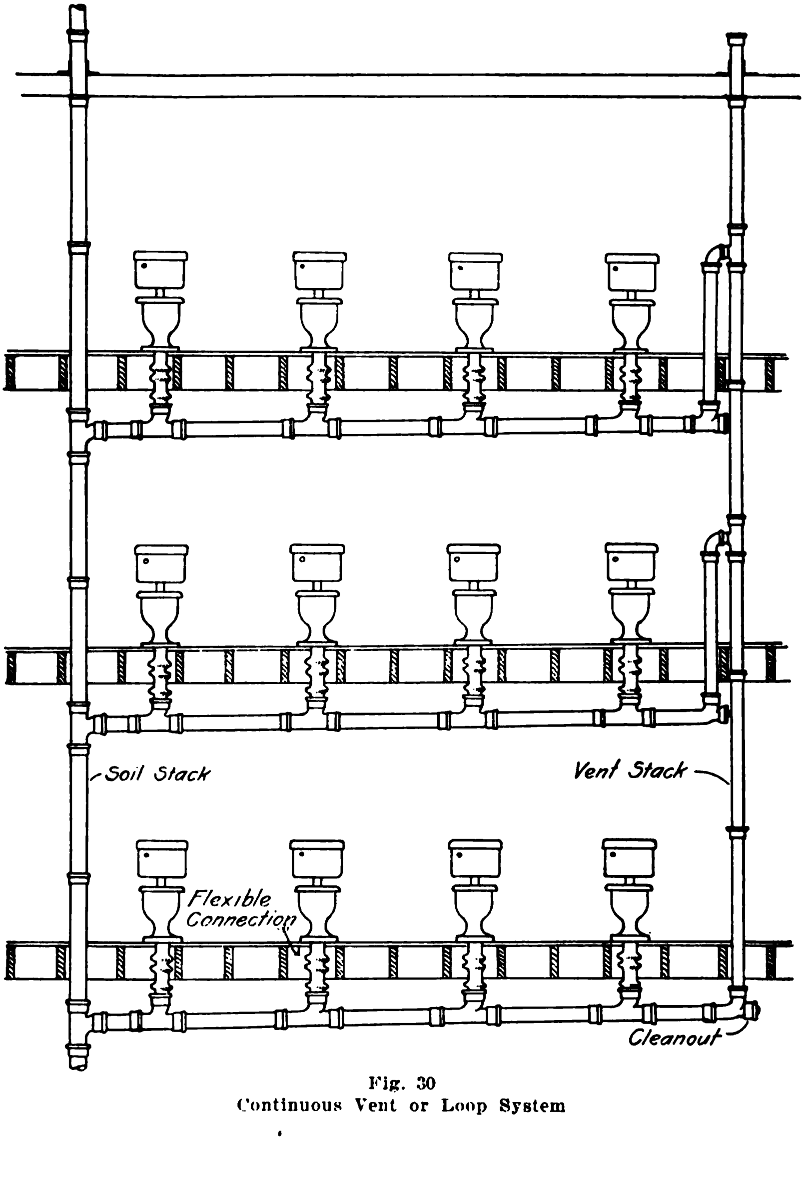


Fig. 30
Continuous Vent or Loop System

closet or closet connections, will be racked out of position so they will leak, or be broken.

The question often arises, which is the best system of plumbing to adopt in a city code. It may be stated that there is no one system so superior to the others under all conditions that it can be used or recommended to the exclusion of the others. The only way when designing work is to blend them all together, using for certain stacks those systems which will give the best results at the least cost. In a large installation it is possible that all three methods might be used in different parts of the work.

It is results that are wanted, and the best method for that particular purpose should be used regardless of the name or reputation of the system. No system, it might be added, is peculiar to itself, but they are all blended together by modifications, as will be seen in the examples of systems, so that it is hard to tell to what system some installations belong.

CHAPTER VIII
EXAMPLES OF DRAINAGE SYSTEMS

ROUGHING-IN FOR SINGLE BATH ROOMS.—The drainage system for a cottage or small building of any kind is a comparatively simple matter in designing and in which there is but little danger of going astray. In large office buildings, hotels, institutions or buildings of like character, particularly when many stories high, there is grave danger of having trouble with the soil and vent stacks if they are not properly proportioned and installed. With the view of making the subject as simple as possible, a number of illustrations are here presented, as types of roughing-in.

Fig. 31 shows how the work can be roughed-in for the bathroom fixtures when the closet is between the bath tub and the lavatory with the least possible amount of pipe, without resorting to back venting, and so no waste pipe will show in the rooms except where they extend from fixture to wall or floor. While no back vents or loop vents are used in this system the work is perfectly sanitary and ordinary siphon traps may be used without danger of siphonage. It will be noticed that both the waste to the bath tub, and to the lavatory are taken from the soil pipe at a higher level than the closet outlet, consequently they cannot be siphoned by the discharge of the closet, which gets a plentiful supply of air from the stack. On the other hand, the closet cannot be siphoned by discharge from the other fixtures because they discharge into so large a pipe they can set up no siphonic action.

It will be well to note the sizes of pipe used in such an installation. The soil stack need be only 3 inches in diameter, likewise the closet bend will be only 3 inches in diameter, which is sufficiently large to care for the discharge of any closet, for closet outlets vary from 1¾ inches to 3 inches in diameter, and average about 2¼ inches diameter.

The manner of roughing-in for these fixtures when the lavatory is between the water closet and the bath tub, is

shown in Fig. 32, which is simply a variation of the arrangement shown in Fig. 31. It does not matter how the fixtures are arranged on the plan, they can be re-arranged or the soil stack can be so located that some modification of these systems of roughing-in can be used. Further, two bathrooms on opposite sides of the partition can be roughed-in exactly like these, duplicating the branches but not the stack.

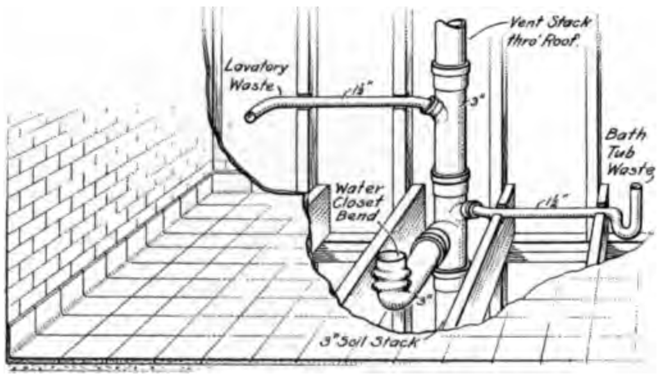


Fig. 31
Simplified Roughing for Bath Room

DISTANCE FIXTURE CAN BE FROM STACK.—Of course there is a limit to the distance a fixture can be located from the soil stack without venting when the foregoing methods of roughing-in are used, and this limit is set by the limitations of the trap itself. This will be understood by referring to Fig. 33, which shows an ordinary siphon trap attached to a piece of pipe. It will be noticed that the distance from the top of the pipe to a level line *a-b* is marked 3 inches, which represents a depth of seal in the trap of 1½ inches, and the inside bore of the trap, which is 1½ inches, making a total of 3 inches in all. Now the trap for a fixture can be set at such a distance from the stack that the waste pipe will not have more than 3 inches fall. With a fall of 3 inches, as shown in the illustration, the long leg of the trap of siphon is just on a line with the line *a-b;* any further dip would make the connection a true siphon and draw the water out of the trap every time the fixture was

discharged. As a matter of fact, the top of the pipe should never be carried down clear to the bottom line in practice, for the seal in the trap is then so nicely balanced that it is easily siphoned. The total distance the waste pipe from an ordinary 1½-inch siphon trap can "fall" is 3¼ inches, and 2½ inches is the extreme amount that should be allowed in practice.

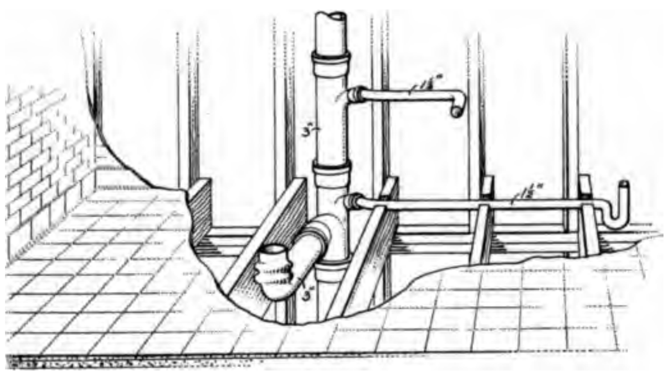


Fig. 32
Simplified Roughing for Single Bath Room

With a possible fall of 2½ inches, the distance the trap can be located from the stack will depend on the fall per foot allowed, and the fall per foot will depend on the location of the pipe. For example, the waste pipe to the lavatory could be run at a pitch of ½ inch per foot, or even less, so that five, six, or even seven feet at a pinch could be reached. When the pipe is run under the floor in wooden joist construction, on the other hand, there is another limiting factor. Twelve-inch joists, the size commonly used in residence work, shrink upon seasoning or drying, about ½ inch. On this account, whenever a waste pipe is run under a wooden floor, it should have a fall of at least ¾ inch, no matter how short it may be. Suppose for instance, the waste pipe is only 1 foot long, and has a fall of ¾ inch. Then, when the shrinkage takes place and the weight of the tub has pressed down the waste pipe, it will still have ¼ inch out of the original ¾ inch fall. Waste pipes laid under

the floor should then have a fall of ½ inch to the foot, with an extra ½ inch allowance for the entire line. Allowing, then, 1 inch for the first foot, and ½ inch for each succeeding foot of waste pipe under a floor, and a total available fall of 2½ inches, the greatest distance from the stack a trap could be located would be 4 feet, although it might be stretched to 7 feet when necessary.

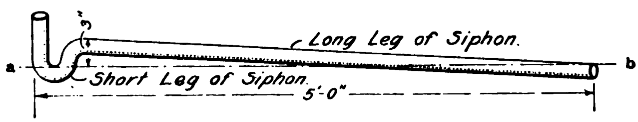


Fig. 33
Length of Siphon Trap that can be used

The objection might be raised that five to eight feet is too much pipe to go unvented. Ventilation, however, is but a compromise, a safety device which is unnecessary in this case. Diffusion from the soil stack will keep the pipe free from strong gases, and every time the fixtures are flushed the pipes will be scoured and the air expelled. It will be safe to assume, therefore, that 8 feet of 1½ inch waste pipe can be run to a fixture that wastes to the wall without being vented, or 5 feet to a bath tub or other fixture that wastes through the floor.

ROUGHING-IN FOR BATH ROOMS ON TWO FLOORS.—The simple method of roughing-in for single bath rooms outlined in preceding paragraphs is shown in Fig. 34 applied to two bath rooms located on two floors, one above the other. It will be noticed that 3 inch soil pipes are being used, and are found sufficiently large. The layout is the same as explained for the single bath room except that two pipes are here run, and one bath room discharges into one of the vertical pipes, while the other bath room fixtures discharge into the other line of pipe.

This same layout could be used for four bath rooms, two on each floor, and on different sides of the partition in which the stacks are run. In that case, all that would be necessary would be to increase the size of stacks to 4 inches diameter, and use double pipe fittings where single TY fittings are now shown.

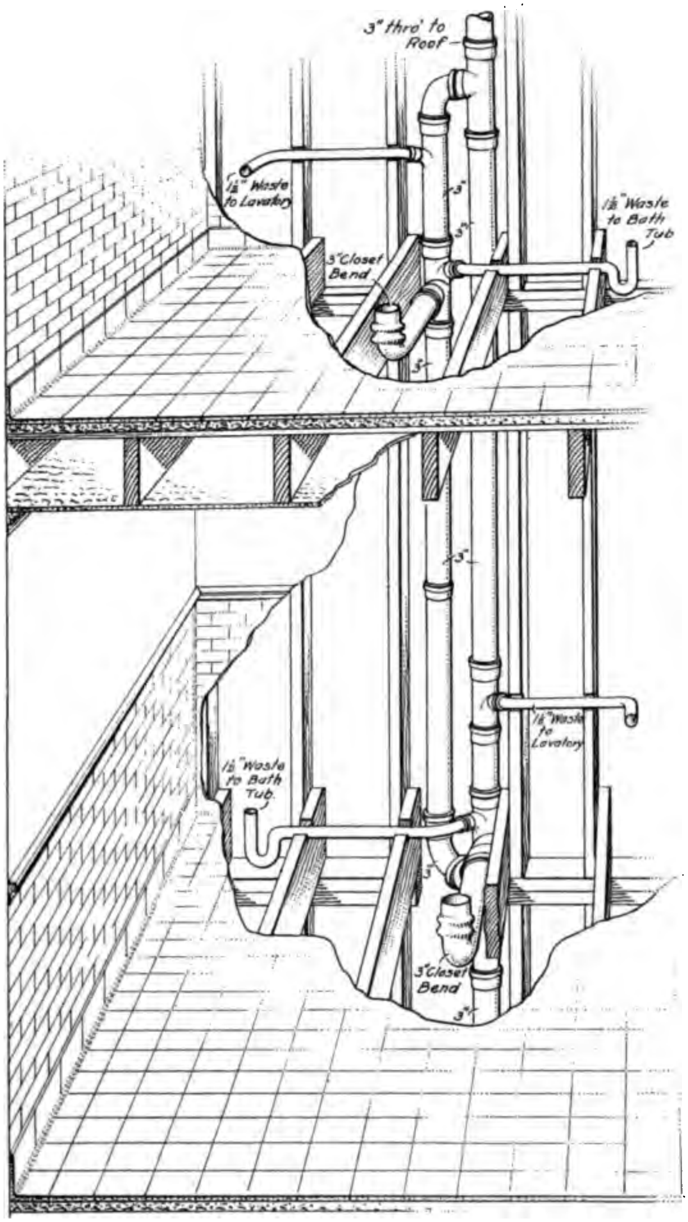


Fig. 34
Simplified Plumbing, Two Floors

ROUGHING-IN FOR LAVATORIES.—When two lavatories or similar fixtures on one floor are located on opposite sides of a partition, and there are no other fixtures above that floor, they can be cheaply, neatly and properly connected as shown in Fig. 35. By this method of installation no pipes are exposed outside of the partitions and each trap is effectively ventilated. It should be borne in mind, however, that a sanitary cross or double TY fitting, as shown in the illustration, must be used with this method of installation. If a double Y fitting, as shown by dotted lines at *a*, were used instead, the waste pipes *b* from the traps would form long legs of siphons that would empty the trap at each discharge from the fixture.

When lavatories or other fixtures on two floors are located on opposite sides of a partition, they can be properly and economically connected as shown in Fig. 36. In this method of installation, separate waste stacks are run to the fixtures on the different floors, and the stacks continued up to the roof to serve as vent pipes. It is simply applying the principles of Fig. 35 to fixtures on opposite sides of partitions on two floors. In Fig. 37 fixtures are located on opposite sides of a partition on three or more floors. It would be too cumbersome and expensive to carry separate stacks to each floor as is done in Fig. 36, so a soil stack and vent stack are run, and between the walls of the partition, at the intermediate floors, the vent stack is connected to the waste stack and a sanitary cross in the connecting branches used on the same principle as in Fig. 37. On the first floor both fixture wastes are connected direct to the vent stack. This is to simplify the construction and wash out of the vent stack any

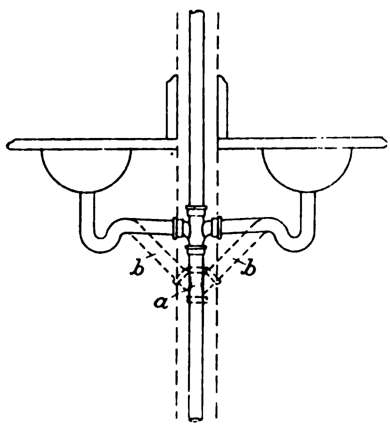


Fig. 35
Roughing-in for Double Lavatory

rust scales or other foreign matter that might lodge there. On the top floor both fixture wastes are direct connected to the waste stack. This makes a perfectly sanitary connection and simplifies the construction. All of the examples of roughing illustrated possess the additional advantage of having concealed in the partition all waste and vent pipes except the short lengths of waste pipe from the fixture traps to the wall; furthermore, when the waste pipe to the fixtures is extended back through the wall, it leaves the floor space beneath the fixtures free from pipes.

EXAMPLES OF ROUGHING IN TALL BUILDING.—The examples of roughing-in for fixtures heretofore given were for small or medium sized installations, where simplicity and economy were the keynotes. It must be remembered, however, that different rules and principles must be observed in roughing-in for fixtures in small buildings, than will be required for skyscrapers. In tall buildings the sewage must fall such a distance from the top floors that it will have a tremendous velocity and the sewage traveling at this high speed will not only compress the air before it, but will entrain air, carrying it along in its wake, thereby creating a partial vacuum back of the large discharges.

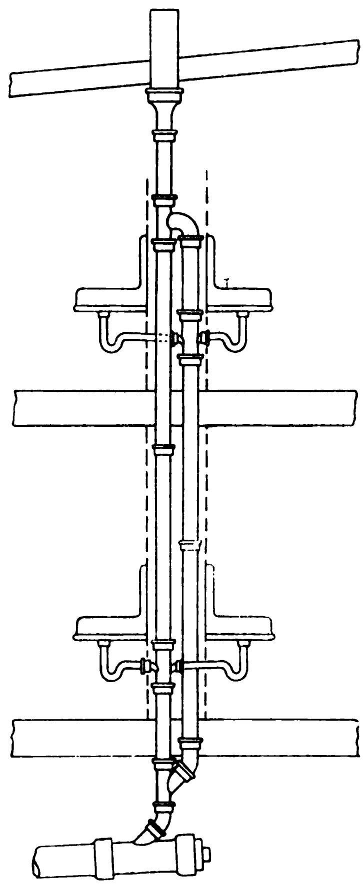


Fig. 36
Roughing for Fixtures on Two Floors

To provide for such conditions, two principles

must be observed. In small work the waste pipes are made smaller than usual, the rule being to proportion them to the volume of sewage they must carry, so they will be self-cleaning, and dispense with vent pipes to as great an extent as possible. In tall buildings, on the other hand, where on account of the high velocity in the vertical soil stacks, from a capacity standpoint the pipes could be reduced to very small dimensions as a matter of fact they must be made larger than for corresponding number of fixtures in low buildings, and vent pipes must be plentifully provided, to keep equalized the pressure of air in all parts of the stack, even when the greatest number of fixtures are discharging simultaneously. It must be borne in mind that the depth of seal in traps is not over 1¾ inches of water, which is equal to a pressure of one ounce per square inch; and if the seal is allowed to be upset, either by pressure or by vacuum, drain air will flow into the building, or there will be a gurgling noise.

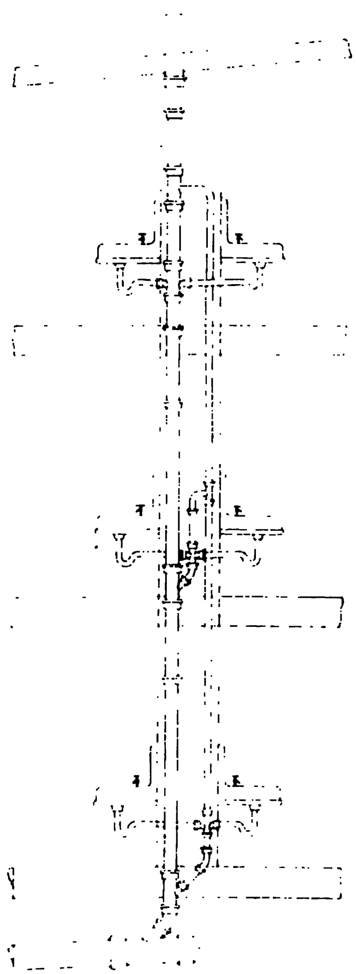


Fig. 37
Roughing for Fixtures on Three or More Floors

To prevent such a possibility, the system should be so proportioned that at no time will there be a greater pressure or vacuum than that equal to one inch of water within the pipes, which would be equal to

.579 ounce pressure per square inch. This will necessitate much larger pipes than would be required merely to conduct the volume of sewage flowing through the system.

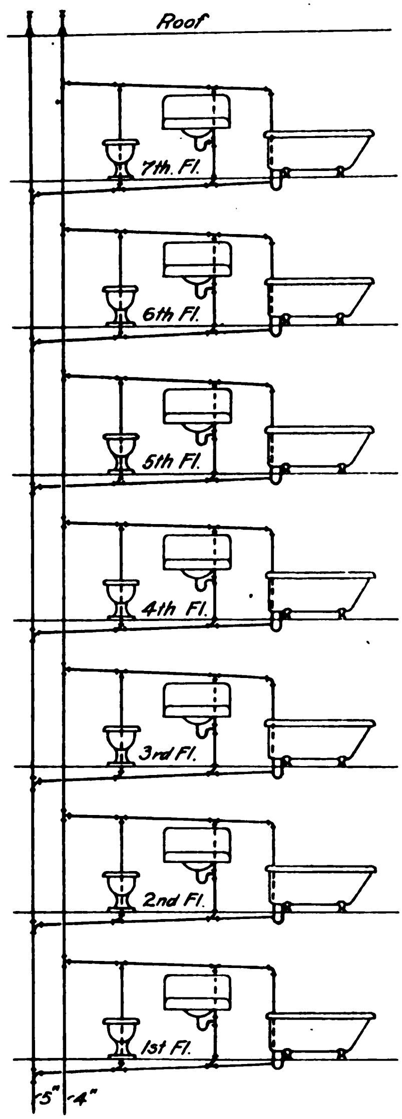


Fig. 38
Stacks and Connections in Tall Building

The roughing-in for a tier of toilet rooms one above another in a tall building is shown in Fig. 38. This work is installed according to the two-pipe system, and it will be observed that the heaved up air in front of a downward flush of water can escape at each floor through the system of back venting, thereby preventing any great pressure inside of the soil pipe, while air is supplied not only from the top of the soil stack above the roof, but likewise from the back vent pipes and vent stack at each floor of the building, as the water descends.

This ventilation of the system is a very necessary provision in all tall buildings, and any economy in that regard will meet with failure. If vents were not provided in the work shown in the illustration, the pressure on the inside of the stack would force air bubbles out of traps of fixtures at the lower floors, and the air would carry water into the fixtures, and in some cases to the floor.

In Fig. 39 is shown an extreme case, but one which frequently occurs in practice, however. A large battery of closets on the top two or three floors of a tall building, then several floors without any fixtures, but a few scattered fixtures lower down in the building. It will be noticed that there are several floors where no outlets for fixtures are taken from the soil stack. Now then, if no relief was provided, the downward rush of water when most of the fixtures on the top floors were flushed would create sufficient pressure within the pipe to force water out of the traps on the lower floors. To prevent such a possibility, it is well to provide relief pipes at the floors where there are no fixtures, the relief pipes being not less than 3 inches in diameter, and connecting together the soil and vent stacks, but in such a manner that sewage cannot flow into the vent stack. It is not absolutely necessary to have these relief pipes at every floor of the building where there are no fixtures, but they should not be more than three floors apart at most, while two would be better, and each floor would do no harm.

SIZE OF SOIL AND WASTE STACKS.—Under ordinary conditions, in small buildings, soil or waste stacks need not

be larger in diameter than the largest branch discharging into them. However, in the case of large buildings many stories in height and with many fixtures connecting to a

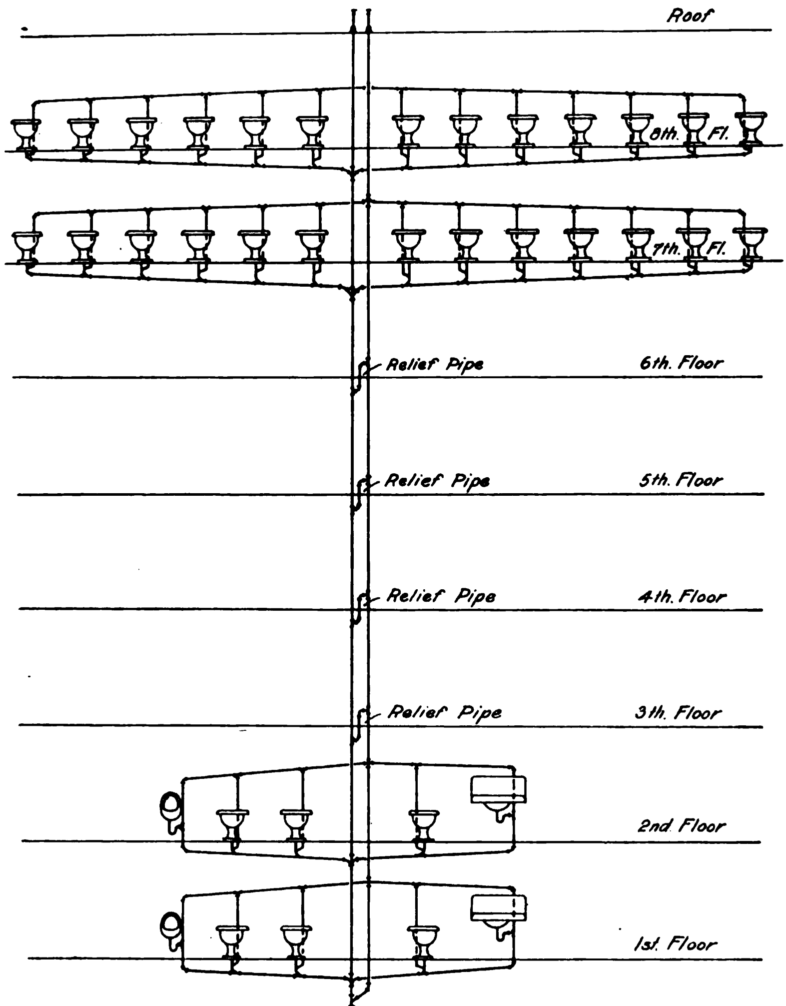


Fig. 39
Relief Pipes in Tall Buildings

stack, the size should be determined by some rule or formula based on the use to which the stack is to be put, and the volume of water it must care for.

There is a principle underlying the proportioning of soil stacks the same as for proportioning other pipes through which liquids or gases flow, but in seeking for this formula the function of the vent stack must not be confused with that of the soil stack, and the effort made to have one pipe serve the purpose of both. The soil stack must be large enough to safely care for the largest flush of water it will ever receive, while, as previously pointed out, the vent stacks and relief pipes must take care of the supply of air, and maintain an equal pressure of not more than one inch of water throughout the system. In the devising of a formula for soil stacks, experimental data should be the basis, the same as it is in all other branches of hydraulics and penumatics, and in the formula, a sufficient factor of safety should be allowed, so the stacks will perform their functions under the severest conditions.

In the present state of the art, the practice, in some cases, is to make the soil stacks as large, or nearly as large, as the main house drain, basing the sizes of stacks on guesswork. That stacks proportioned in that way are unnecessarily large will be apparent on little reflection. The house drain is proportioned to carry off all the water discharged into it from all sources, rain leaders included, assuming that the entire flow will reach a certain point about the same time without intervals between flushes. Further, it is proportioned to carry off this quantity of fluid when the velocity in the drain is not greater than 6 feet per second, and the average velocity 4½ feet per second. That is the velocity due to the pitch or fall of the pipes.

It would seem that the method of proportioning the main house drain would be equally applicable to the stacks of soil and waste pipe, and that if they are made of sufficient capacity to care for the maximum discharge, they will always be well flushed without danger of being overtaxed. It is not likely that such a condition will ever obtain in any plumbing system, of the entire quantity of fluid allowed for reaching a certain point in the stack at one time. So rapid is the descent of water in vertical stacks that a start of but a fraction of a second will suffice to separate the various

flushes, and even if the effort were made, it would be almost impossible to so time the various flushes that they would all meet so as to form a solid plug of water in the pipe. Assuming, however, that they did, the increased hydraulic head would instantly be converted into velocity head and the entire column would flow away with greater rapidity, thus increasing the capacity of the pipe.

In proportioning a vertical stack, a velocity would have to be assumed. In the house drain, we take the velocity due to the pitch or fall of the pipe. In the vertical stacks, we might take part of the velocity due to gravity when matter falls through the air. For example, matter in falling through a pipe travels with an accelerating velocity of about 32 feet per second. If, however, we ignore the acceleration and assume that sewage in a pipe falls with a uniform velocity of 32 feet per second, less the frictional resistance due to the walls of the pipe, and allow 12 feet of velocity for friction head, we will have a velocity of 20 feet per second in our vertical stacks. This would seem to be a safe velocity to assume for, as factors of safety we would have not only the acceleration due to gravity but also the hydraulic head, if the bore of the pipe should ever become full, forming a solid plug of water.

Accepting 20 feet per second, then, as the velocity of flow down the vertical stacks of soil and waste pipe, and assuming a maximum flow of 25 per cent. of the greatest quantity of water which can be discharged per second into a stack from all the fixtures with which it is connected, then proportioning the stack to take care of that quantity of fluid, the pipes would be of sufficient diameter to properly fulfill their functions.

In the case of buildings 25 stories and more in height, it might be advisable to allow for more than 25 per cent. of the fixtures being used at one and the same time. Not that there is likely to be, but owing to the pressure the descending water might cause in the heaved up air ahead of it, an extra allowance of space would do no harm. However, if the vent stacks are properly proportioned, they will take care of all pressure, and a 25 per cent. allowance will

be sufficient. It is well to bear in mind, however, that this rule, like all rules and formulas, must be used with judgment, the system of venting used having much to do with the result.

Of course, there must be a minimum size of pipe, nothing smaller than which should be used. Experiment, no doubt, will develop the fact that 2½-inch pipe is the smallest that can be used, and will be suitable only for small, one bath room residences; but in the absence of experimental data, experience must be the guide. At the present time, numerous installations of 3-inch soil pipe, which have been in successful operation for years, point to the fact that soil pipes of this diameter are large enough for private houses and for vertical stacks in many other buildings. New York City, for instance, allows four water closets to discharge into a 3-inch soil pipe.

For the purpose of checking the 20-foot per second velocity method, assume a building five stories high, with toilet rooms on each floor, each toilet room containing 10 closets. Twenty-five per cent. of the closets are supposed to discharge 1.33 gallons of water each per second, and at such intervals that the waters will come together to form a solid core in the pipe. On that assumption the stack would have to care for 1.33 gallons $\times$ ¼ of 50 closets, = 16.62 gallons of water per second. A 4½-inch pipe will care for 16.52 gallons of water per second at a velocity of 20 feet per second, while a 5-inch pipe will care for 20.77 gallons per second. It will be seen that the 4½-inch pipe is slightly under the requirement, while the 5-inch pipe is slightly above what is actually needed, and allows an additional margin of safety. As a rule, therefore, it is better to use the large pipe having the full capacity required, although in some cases a 4½-inch vertical stack of soil pipe would be sufficiently large for this purpose. In tall office buildings 30 to 50 stories in height, it can be assumed that about one-third to one-half of the closets will be discharged at once.

It will be found safe to assume that only 25 per cent. of the fixtures in ordinary buildings, and 33 to 50 per cent.

in extremely tall buildings are discharged at the right moment for the water to intermingle and form a solid plug in the soil stack, for it is doubtful if over 20 per cent. of the closets will ever be operated so as to bring about this result, and even if more than 25 per cent. happened to coincide in that manner, as was previously pointed out, there would still be a sufficient margin of safety to take care of the extra water. It would seem, therefore, that proportioning soil and waste stacks according to this method would prove perfectly safe and eminently satisfactory, at all events until such time as experimental data will furnish more definite information upon which to base a better method or devise a more accurate formula.

SIZE OF VENT STACKS.—The practice of making vent stacks only one size smaller in diameter than the corresponding soil or vent stack is a sound one, which will give good results in a system of any size. In medium size buildings, smaller stacks may be used, but in extremely tall buildings, forty, fifty and sixty stories in height, the inlet is so far away from the fixtures on the lower floors, the friction is so great, and the necessity for maintaining a low pressure of not over 1 inch of water so important, that larger vent stacks are called for. There is no economy in making the vent stacks small, for, in proportion as the size of the vent stacks are decreased, the soil or vent stack must be made larger to compensate for the lack of capacity in the vent stack. It is doubtful if in medium size buildings the same principle would not hold true, and that by making the vent stacks large the soil stacks may be smaller. At all events, when the method of proportioning soil and vent stacks given in the preceding article is followed, the vent stack to accompany the soil stack must be only one size less in diameter.

Vent stacks should never be smaller than 2 inches in diameter. When the accompanying soil or waste stack is 4 inches or larger in diameter and the building low, according to current practice, the vent stack need have an area of only one-fourth (a diameter of one-half) that of the soil or waste pipe. The reason vent stacks, under such conditions,

can be smaller than soil or waste stacks is that air flows more than four times as readily as water, hence, enough air can flow in a vent pipe of given size to prevent a vacuum forming in a soil or waste pipe of four times its capacity. In tall buildings, however, it is not only prevention of siphonage, but what is far more serious, the prevention of pressure from the descending water which must be guarded against, therefore, large vent stacks are necessary. The proper size of vent stack to accompany any size soil or waste stacks can be found in Table XVI.

TABLE XVI. Size of Vent Stacks

Diameter of soil or waste stack in inches........	2	3	4	5	6	7	8	9	10	11	12
Diameter of vent stack inches, low building ..	2	2	2	2½	3	3½	4	4½	5	6	6
Diameter of vent stack in inches, tall building...	2	2½	3	4	5	6	7	8	9	10	11

SIZE OF SOIL AND WASTE PIPES.—Soil and waste pipes should always be the full size of the waste outlets from fixtures. The outlets should be sufficiently large to permit the fixtures being emptied quickly so as to thoroughly flush the waste pipes, and the waste outlets should be unobstructed by strainers, cross-bars or other devices that will catch fibrous materials or obstruct the flow of water. Formerly water closet outlets were made 4 inches in diameter and soil pipes were made correspondingly large; however, the manufacture of closets has undergone a change both as to types and sizes, and water closets are now made with traps seldom over 3 inches, and usually only 2½ inches in diameter. In consequence of this change in the size of closet traps, soil pipes need now be made only 3 inches in diameter, and soil stacks in ordinary cottage buildings may be made the same size. A distinct advantage gained by this reduction in size of closet traps and soil pipes is that soil stacks in small buildings can more easily be concealed in partitions now than formerly when 4-inch pipes were used.

SIZE OF VENT PIPES.—For traps 3 inches and more in diameter vent pipes 2 inches in diameter are used; for 2-inch trap, a 1½-inch vent pipe is used, and for any trap smaller than 2 inches in diameter the vent pipe should be the full size of the trap, to reduce the possibility of stoppage should the waste pipe become choked and sewage back up in the vent pipes.

From experience and experiment the sizes of soil, waste and vent pipes shown in Table XVII are derived.

TABLE XVII. Sizes of Soil, Waste and Vent Pipes

Kind of Fixture	Diam. of Soil of Waste Pipe in Inches	Diam. of Vent Pipe in Inches
Water closets	3	2
Bath tubs	1½	1½
Lavatories	1½	1½
Bidets	1½	1½
Shower baths	1½	1½
Sitz baths	1½	1½
Slop sinks	2 to 3	1½ to 2
Kitchen or pantry sinks	1½ to 2	1½
Laundry trays	1½	1½
Urinals	1½	1½
Drinking fountains	1¼	1¼

Waste pipes from fixtures to the stack should have as much fall as can be conveniently given; owing to their small diameters and the proportionally large amount of frictional resistance they offer to the flow of sewage they cannot be given too much pitch.

EXPANSION OF SOIL AND WASTE STACKS.—When soil and waste stacks are installed in high buildings, local conditions might be such that allowance should be made for expansion and contraction; under ordinary conditions, however, in buildings of moderate height no special provision need be made for expansion; the spring of wrought-iron pipe and soft lead joints to cast-iron pipe compensating for any variation of length due to temperature. As a matter of fact, the range of temperature during the year should not vary 40 degrees Fahr. It is doubtful if it would vary half that much, but assuming a variation of temperature

during the year of 40 degrees Fahr., the expansion of a wrought iron pipe in a building 50 feet high would be less than three-sixteenths inch. The vertical parts of a building, however, are subject to very much the same range of temperature as the pipes, and the entire building will expand correspondingly with the pipes, so that relatively there is little or no expansion to be considered.

SETTLEMENT AND SHRINKAGE OF BUILDINGS.—While special provision need seldom be made for expansion and contraction of soil stacks in low buildings, some provision should be made to allow for settlement of a building and shrinkage of the floor joists without damage to the fixtures or to the drainage system. Pipes should be kept free from structural beams and connections to stacks should be made with swing, expansion, or flexible joints to allow for settlement and shrinkage.

The amount of settlement and shrinkage in buildings, and the damage resulting therefrom, seem to be little understood or not fully realized in plumbing practice, although the breakage of re-vents from closet traps above the floor which made them abandon the back-vent from the horn of porcelain closets, ought to have taught the lesson well.

There are three distinct movements which take place in all buildings. They are, shrinkage of the floor joists; settlement of the building, and movement caused by expansion and contraction. For instance, all tall and heavy buildings erected on other than bed-rock, settle from three to five inches, due to the compressibility of the soil. Evidence of this subsidence of buildings can be seen in the cracks which appear in walls, floors, ceilings and tiling of most buildings, showing unmistakably that some movement has taken place since the building was erected.

If the subsidence of buildings constituting the greater part of the business portion of the city of Chicago continues, that city will have not one but scores of leaning towers. The Building Department there declares that virtually all of the immense buildings and sky-scrapers of the downtown district are "out of plumb and lean out far over the plumb-line."

The Great Northern Hotel is partially carried on jacks, as are a number of other buildings, which, periodically, as they settle, are jacked up. When the buildings will settle no further, the walls will be filled in with masonry and the jacks removed.

It is probably safe to say that every tall building in the city leans more or less, and if they are on floating foundations they also settle gradually. That is, there are two destructive movements in the subsidence of tall buildings carried on floating foundations. In the first place, they gradually lean from the plumb, due to wind-pressure or other forces acting upon them, and this whether carried on floating foundation or built on solid bed rock; in the second place, when on floating foundations, they settle, due to their weight.

But there is still another movement of tall buildings not yet mentioned, and this new movement cannot be better described than by quoting the following article:

"If one remembers that an inch, although a good deal on a man's nose, is very little in a hundred feet, one will not be surprised to learn that all high structures sway in the air. The Eiffel Tower swings perceptibly with the wind, and even stone shafts like those of Bunker Hill and Washington Monuments move several inches at the top. In these cases the cause of the action is not only the wind, but the heat of the sun. The side that is towards the sun expands during the day, more than the side in shadow. An interesting device has been employed to show the movement of the dome of the Capitol at Washington. A wire was hung from the middle of the dome inside the building, down to the floor of the rotunda, and on the lower end of the wire was hung a 25-lb. plumb-bob. In the lower point of the plumb-bob was inserted a lead pencil, the point of which just touched the floor. A large sheet of paper was spread out beneath it. As the dome moved, it dragged the pencil over the paper every day. The mark made was in the form of an ellipse six inches long. The dome would start moving in the morning as soon as the rays of the sun began to act upon it; and slowly, as the day advanced, the pencil

would be dragged in a curve across the paper until sundown, when a reaction would take place and the pencil would move back again to its starting point. But it would not go back over its own penciled tracks, for the cool air of night would cause the dome to contract as much on the one side as the sun had made it expand, and so the pencil would form the other half of the ellipse, getting back to the original point all ready to start out again by sunrise."

The third and final movement of buildings is shrinkage. So far as strictly fireproof buildings are concerned, there is no shrinkage to be taken into consideration. However, 97 per cent. of buildings have wooden floor construction, and the shrinkage of the joists is a serious problem in plumbing, which has caused the breakage of hundreds of thousands of closets.

When a building is erected, the joists are green and unseasoned. Even if dry when put in, by the time the building is enclosed the joists have been rained upon and wetted by the plaster and mortar so they are saturated and swollen. While in this condition, the floors are laid and the beams then dry out and shrink. This shrinkage may be seen in the doors which stick and will not close; the floors which have receded from the base board, leaving a gaping opening in which one can put his fingers; casings which open at the joints, and cracks which appear in the plaster of partitions supported by the floors. The plumbing likewise is affected by the shrinkage. If the closet connection is a rigid one—which it ought not to be—when the shrinkage occurs the soil pipe will either be pushed down, damaged or broken, or the closet held above the floor line a distance equal to the shrinkage. When connected up with a flexible or collapsible fitting of any kind, the closet base always remains on the floor both before and after shrinkage, and the fixture or piping are in no way damaged. When closets are held above the floor line by a rigid connection, on the other hand, breakage often results.

In Table XVIII can be found the amount building timbers shrink upon drying. It will be noticed that 12-inch joists, the kind commonly used in residence work, shrink

.48 or practically ½ inch, while the larger sizes shrink even more. The 20-inch joists, a size often used in business buildings, shrink over ¾ inch.

OUTLETS TO STACKS ABOVE ROOF.—In cold climates vent stacks should be increased in size where they pass through the roof. If they are less than 4 inches in diameter they should be increased to 4 inches; and if they are 4 inches or larger in diameter they should be increased one size before passing through the roof. The object of increasing the size of vent stacks where they pass through the roof of a building is to reduce the possibility of the outlets becoming choked with hoar frost during cold weather. The increase in size should be made at least 1 foot below the under side of the roof, and a long increaser fully 16 inches long should be used. In cold climates vent stacks should not extend more than 12 inches above the roof, as there is greater probability of becoming choked with hoar frost where the pipe is exposed.

TABLE XVIII. Shrinkage of Timbers

Size of Green or Wet Timber	Amount Lost by Shrinkage 4%	Size or Depth of Timber When Dry
6 inch	.24	5.76
8 inch	.32	7.68
10 inch	.40	9.60
12 inch	.48	11.52
14 inch	.56	13.44
16 inch	.64	15.36
18 inch	.72	17.28
20 inch	.80	19.20

ROOF FLASHINGS.—Where vent stacks pass through a roof the opening around the pipes should be made perfectly storm-tight, by flashings of sheet lead or copper. A good method of flashing for use in most climates is shown in Fig. 40. This consists of a collar *a* of lead soldered to a flange *b* at the same angle as the pitch of the roof; the top edge of the collar is made tight around the pipe by working a bead *c* tightly around the pipe with a gasket *e* of asbestos packing

and white lead in between. This makes not only a tight connection, but also a flexible one that is not affected by a settlement of the pipe.

In severe climates, where there is danger of hoar frost stopping the outlet of the stack, it can be checked to a great extent, and in some cases entirely prevented by flashing the opening in the manner shown in Fig. 41. In this method the pipe extends to a height of about 12 inches above the roof, and the opening through the roof is made 2 inches larger than the pipe, so there will be a 1-inch space all around it. The collar of the flashing is then made the same size as the hole in the roof, and is turned over and calked into the top of the stack as shown. This construction provides an air space around the pipe which is open to the attic and keeps the temperature of the exposed pipe at about the same temperature as the inside of the building. On tin or copper roofs the outer edge of the flange of either style of flashing should be well soldered to the metal; on tar, cement or asphalt roofs the flange should be placed between layers of roofing material and the finishing course laid upon it. On wooden or slate-shingled roofs the upper edge of the flange should extend at least two courses up under the shingles, and the exposed edges on wood-shingled roofs well tacked down with short nails having large heads.

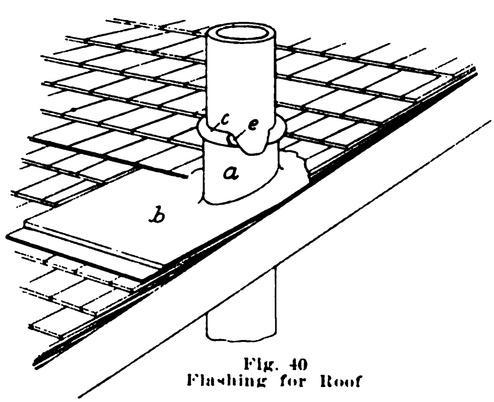


Fig. 40
Flashing for Roof

Sheet copper for flashings should weigh at least 16 ounces to the square foot, and sheet lead at least 6 pounds to the square foot. The roof flange of a flashing should extend at least 6 inches on all sides of the stack. Outlets to stacks above a roof should be free from caps, cowls or

bends, as they obstruct the opening, easily choke with hoar frost, and interfere with the free passage of air. Outlets should be located well away from the windows, doors or ventilating shafts leading to the interior of a building, and, when practicable, should be a reasonably safe distance away from smoke flues. On buildings that have the ordinary pitch roof and on all kinds of roofs in cold climates vent stacks need only extend from 12 to 18 inches through the roof. On buildings with flat roofs having parapet walls the top of the stacks should extend at least 6 inches above the level of the walls. On tenement houses or other buildings where the roof is easily accessible, and used by the inmates, the top of all stacks should be at least 5 feet above the roof, and the outlet protected by a heavy brass wire basket securely fastened to the opening to prevent articles being dropped into the stack.

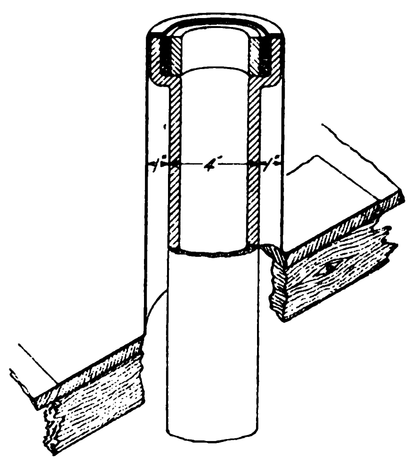


Fig. 41
Roof Flashing for Cold Climate

SUPPORTS FOR STACKS.—Soil and waste stacks should be firmly supported at their base by a brick pier or iron pipe rest placed directly under the stack. If the house drain is suspended from the ceiling beams, a strong iron hanger should be placed on the drain close to the stack and when possible to place two hangers, one on each side of the stack, it should be done. Besides supporting stacks at their base they should also be supported at each floor of the building by heavy iron hangers or clamps securely fastened to the side walls or floor beams. Pipe hooks may be used in small frame buildings, but should not be used in buildings over three stories in height.

MATERIAL FOR STACKS.—Cast-iron hub-and-spigot pipe is generally used for soil waste and vent stacks in buildings

that do not exceed 65 feet in height. In buildings of greater height, wrought-pipe drainage systems are generally installed. The recommending features of this system of piping are, greater and more uniform strength of the pipe, less number of joints, greater strength and permanence of the joints, greater range in the size of pipes and fittings and greater flexibility of the pipes and of the system as a whole.

Wrought-pipe drainage systems differ from other drainage systems only in the materials of which they are constructed and the method of working the materials.

CHAPTER IX
TRAPS AND TRAPPING

Siphon Traps

CLASSIFICATION OF TRAPS.—Traps are fittings used to prevent the passage of air or gas through a pipe without materially affecting the flow of sewage. To successfully perform the functions for which they are intended, traps must be so constructed or protected by vent pipes that they cannot be siphoned or have their seals forced by back pressure under any conditions that obtain in a well constructed drainage system. Furthermore, they should be self-scouring at each flush of the fixtures to which they are connected, and should contain sufficient depth of water to withstand loss by evaporation for a long period of time without breaking the seal.

There are two types of fixture traps commonly used, *siphon traps* and *non-siphon traps*. The simplest type of trap is the running trap of siphon type shown in Fig. 42. It consists of a downward dip in a pipe which fills with water and thus prevents the passage of air. As this water seals the pipe to the passage of air or gases, it is referred to as the seal of the trap. The seal of this form of trap is formed by the column of water *a*, and is seldom over 1¾ inches in depth. It is not a good trap for the reason that it is only capable of withstanding a back pressure of .063 pound per square inch. If greater pressure is applied the water will back up sufficiently in the horizontal inlet to allow drain air to blow through the seal as indicated. The height *b* to which water raises in the inlet end of the trap determines the amount of back pressure required to force the seal. The form of siphon trap most generally used is shown in Fig. 43. It is known as a half S, or P trap. When subjected to back pressure the water in this trap backs up in the vertical inlet leg and reaches a height *b* of 3½ inches before drain air can blow through. This water column will

withstand a back pressure of .126 pound per square inch, or double the back pressure a running trap will stand.

SIPHONAGE OF TRAPS.—The water from a trap may be siphoned in either of two ways; first, by self-siphonage, and second, by aspiration caused by the discharge of other fixtures. As a matter of fact, there is no difference between the siphonic actions in the two cases, as they are both due to the fact that the long leg of the siphon is flowing full of water, or water with air so entrained that it acts as a plunger of water. When the water is siphoned by self-siphonage, the water flowing from the fixture fills the waste pipe to the soil stack, and in that way starts the siphonic action which empties the trap. When a trap is siphoned by the discharge from another fixture, the other fixture must be located on a higher floor; then when the discharge of water passes the branch entrance for the fixture lower down, it fills the stack full, thereby forming a long leg from the trap and waste pipe.

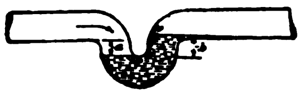


Fig. 42
Running Trap

A trap can lose its seal from self-siphonage only when the waste pipe from the trap to the stack is unventilated and extends below the bottom level of the dip *a* of the trap so as to form the long leg of a siphon as shown in Fig. 44. If the waste pipe extends directly back to the main stack, as shown in Fig. 45, without dipping below the bottom of the dip, the trap could not be self-siphoned because there would be no long leg; and, provided no fixtures discharged into the stack above where the waste connects, no back vents would be required for the trap.

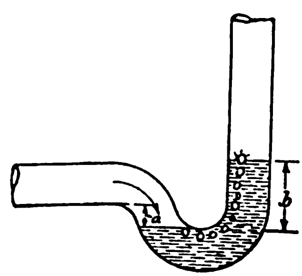


Fig. 43
Half S Trap

LOSS OF SEAL BY MOMENTUM.—Theoretically, a trap may lose its seal by momentum. If a trap is placed directly beneath a fixture, but some distance below it, a flush of

water might acquire sufficient momentum to carry it through the dip of the trap and into the waste pipe beyond. As a matter of fact, however, there are modifying conditions to prevent such loss. Most fixtures as now made have outlets so obstructed by strainers or crossbars that the outlets are of less area than that of the waste pipe, consequently the pipe could not fill full bore and the velocity would hardly be sufficient to acquire the necessary momentum. If it did, no harm would result, as sufficient water would adhere to the long inlet pipe and to the sides of the fixture to again seal the trap. Nevertheless, traps should be placed as close to fixtures as possible, not only to prevent possible loss of seal by momentum, but also to avoid a long stretch of untrapped waste pipe.

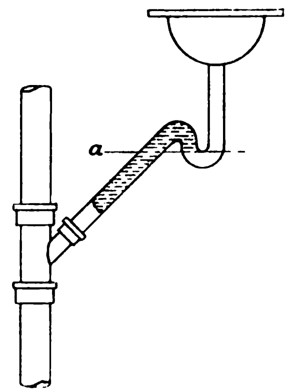


Fig. 44
Self Siphonage

SIPHONAGE BY ASPIRATION.—When unvented siphon traps are used, a trap on one floor of a building may be siphoned by water discharged into the stack from a fixture at a higher level, as shown in Fig. 46. This is called siphonage by Aspiration. The water discharged into the stack at the higher level, in passing the branch to the fixture at the lower level, turns the soil pipe into a long leg for the siphon trap of the lower fixture, as can be seen by the illustration, and loss of seal results.

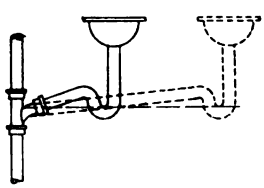


Fig. 45
Half S Trap Connection

EVAPORATION OF WATER FROM TRAPS.—From experiments made by Dr. Unna, Municipal Engineer of Cologne, to determine the length of time required to destroy the seal of traps by evaporation, it can be calculated that under ordinary conditions the seal of an unvented siphon trap with a $1\frac{3}{4}$-inch depth of seal will be destroyed in from four and a half to five weeks' time.

It may be stated, as a general rule applicable to all types of unvented traps, that under ordinary conditions such as obtain in a well-constructed drainage system, the rate of evaporation will average .4 of an inch per week, irrespective of size or shape of the surface exposed. No experimental data are available to show the rate of evaporation of water from ventilated traps, but it would be safe to assume a rate of .8 of an inch per week.

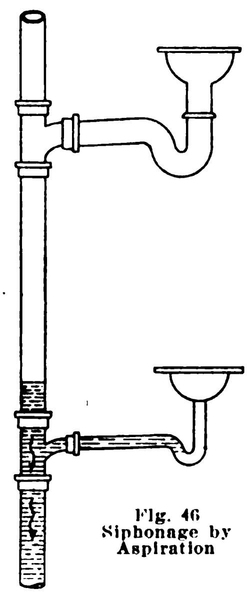


Fig. 46
Siphonage by Aspiration

NON-SIPHON TRAPS. — Non-siphon or refill traps are those in which the seal cannot be entirely destroyed by siphonic action under any reasonable condition of circumstances likely to prevail in a well-installed drainage system. Part of the seal can be siphoned from a non-siphon trap, but sufficient water always remains to effect a seal.

The effect of siphonic action on a drum trap, which is a simple form of non-siphon trap, is shown in Fig. 47. When a partial vacuum is created in the waste pipe, atmospheric pressure forces part of the seal from the trap. When, however, the water in the trap reaches a certain level, no reasonable amount of siphonic influence can lower it more; air then breaks through the seal, dashing the water to all sides. After the vacuum is broken, from all sides of the trap the water settles back in the bottom, thus maintaining the seal. Sufficient water always remains in the bottom of this form of trap to effect a perfect seal. All forms of non-siphon traps are made with enlarged bodies, some of which contain baffle plates to deflect the water from the outlet.

The seal of a non-siphon trap is shown at *a* in Fig. 48, and is the depth of water between the top arc of the inlet pipe, and the bottom arc of the outlet pipe. The full seal is

shown here, although after being subjected to siphonic action, the seal would not be over perhaps ¾ inch.

EFFECT OF BACK PRESSURE ON NON-SIPHON TRAP.—The most common form of a non-siphon trap is a drum trap. In this form of trap the area of the body usually is four times the area of the waste pipe, so that to force the seal by back pressure, sufficient pressure is required to sustain a column of water *b*, Fig. 49, five times the depth of seal *a*. The depth of seal generally is 4 inches, hence to force the seal by back pressure, a pressure sufficient to sustain a column of water 20 inches high is required. This column of water is equal to a pressure of .728 pound per square inch.

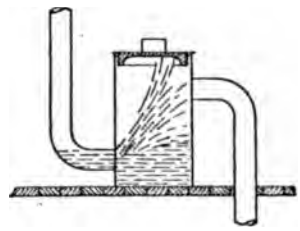


Fig. 47
Effect of Siphonic Action on Non-Siphon Trap

EVAPORATION FROM NON-SIPHON TRAPS is not more rapid than from an equal size siphon trap, and calculated by the constant of evaporation, .4 of an inch per week, it would take, under ordinary conditions, fifty weeks for a 3-inch body drum trap with 4-inch seal and 1½-inch waste pipe to lose its seal.

SELF-SCOURING ACTION OF TRAPS.—The chief objection to non-siphon traps heretofore has been that owing to their enlarged bodies they were not self-cleaning, hence they afforded a fouling place for the deposit of sediment. This objection has to a certain extent been overcome as a result of the discovery that water introduced with a rotary motion to the enlarged chamber thereby scoured it.

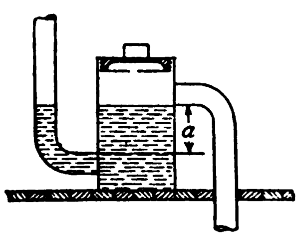


Fig. 48
Seal of Non-Siphon Trap

GREASE TRAPS.—Grease traps are separators in which grease, fats and oils are separated from greasy waste water, the grease being retained in the trap while the water escapes to the drainage system. They are used in connection with kitchen, scullery or other sinks, into which large quantities of greasy water are emptied, to

intercept the grease while in a fluid state and thus prevent its adhering to the waste pipes, where it would congeal and successive deposits in time choke the pipe.

CONDITIONS GOVERNING USE OF GREASE TRAPS.—Grease traps should be used to intercept the grease from all kitchen sinks in cities that have installed systems of sewerage from which storm water is excluded. Under such conditions, the sewers are so small and so poorly flushed that great liability would exist of partial or complete stoppage from the grease if grease traps were omitted. When a city has installed a combined system of sewer and storm water drains, grease traps may be omitted if the kitchen sink is not over fifty feet from the street sewer and the main house drain runs through the cellar exposed to the heat of a furnace. However, when the sink is over fifty feet from the street sewer, or when the main house drain is buried in the earth, so grease would be likely to chill before it reached the street sewer, grease traps should be used. Also they should in every case be used in all large institutions, boarding houses, hotels and bake shops or other buildings where large quantities of grease are liable to find their way into the drainage system.

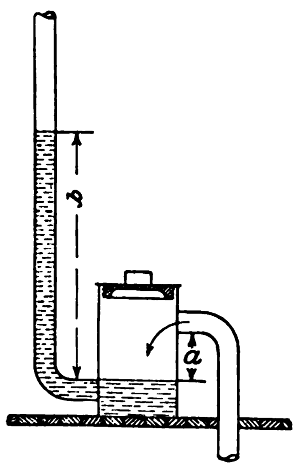


Fig. 49
Effect of Back Pressure on Non-Siphon Trap

LOCATION FOR GREASE TRAPS.—A grease trap should be located as close as possible to the sink from which it receives the discharges. It should not be placed in the kitchen, however, on account of the offensive odors that would enter the room every time the trap was opened to remove the grease. In detached dwellings, grease traps usually are made of brick and placed outside the house. A better practice is to make the trap of iron and locate it in the cellar or basement, safe from frost and close to the source of grease.

SIZE OF GREASE TRAPS.—Grease traps to be effective must have at least twice the capacity of the greatest quantity of greasy water likely to be discharged at one time into them. This is so that the entering water will be chilled and the grease congealed and rise to the surface of the water, thus being retained in the trap. If the grease traps are too small, part of the entering water will pass through the outlet into the drain before it is sufficiently cooled, carrying with it whatever grease it holds in suspension, which will adhere to the pipes. In ordinary residences, a dishpan full of greasy water is the greatest quantity likely to be emptied at one time, and if the grease trap is made to hold at least twice that quantity, it will fulfill all requirements. In hotels, clubs and other large institutions where a great many people are fed, the probable amount of greasy water liable to be discharged at one time must be estimated, and the grease trap made with a capacity of twice that amount.

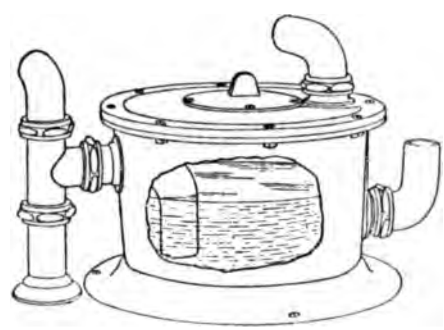


Fig. 50
Grease Trap

TYPES OF GREASE TRAPS.—There are two types of grease traps in use: An ordinary trap with large intercepting chamber, as shown in Fig. 50, and a water jacket grease trap, Fig. 51, around which cold water circulates to chill the water in the trap. The water for this purpose is taken from the cold-water supply pipe, and must pass through the water jacket of the grease trap before being drawn from a faucet. When a water supply pipe is connected to a grease trap for this purpose, it should be continued to some unimportant fixture, or else connected to the hot-water tank, as water that passes through a grease trap jacket absorbs heat from the water within the trap and becomes disagreeably warm for most domestic uses.

SLIP-JOINTS.—Joints in which one pipe or member

slips inside of another and the junction between the two is made tight with a gasket compressed by means of a screw thread or bolts, are known as slip-joints. Any joint in which the parts are not bound together, but one part may be slipped out of place, having nothing to overcome in doing so but the resistance of the grip of the compressed gasket, should be classed as a slip-joint no matter what its use.

Slip joints are permissible and very convenient when used on the house side of a fixture trap. Under no condition, however, should a slip-joint be permitted on the sewer side of a trap, particularly on the sewer side of a water closet trap. Indeed, a gasket joint of any kind should not be permitted on the sewer side of any trap, and a slip-joint, which is the least secure of all forms of gasket joints, is the most objectionable joint of them all. The rule can be laid down that under no condition should a gasket joint of any kind be permitted on the sewer side of any trap. If a gasket is used, no further evidence need be looked for. The gasket alone stamps it as insanitary. Attention should be called here to the fact that water closets are set with a putty joint, gasket, or sometimes a slip joint, which is extremely bad practice.

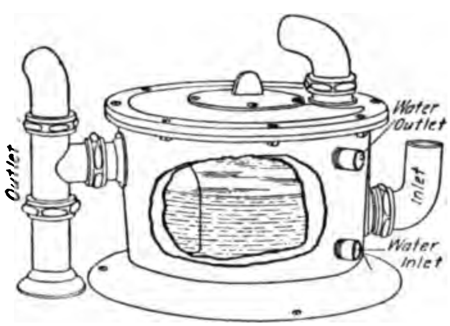


Fig. 51
Water Jacket Grease Trap

DISTANCE OF BACK-VENT FROM TRAP.—The distance the back-vent can be placed from a trap without danger of the trap being self-siphoned depends entirely on the fall to the waste pipe from the trap to the stack. If the fall is slight, the vent pipe can connect to the waste pipe further away from the trap than when the fall is great. The rule is: Connect the back-vent to the waste pipe at such a point that the vent opening will be above the level of the water

in the trap. There will then be no long unventilated leg to form a siphon.

The application of this rule can be seen by referring back to Fig. 45, which shows two traps, one in solid lines, the other in dotted lines, each a different distance from the soil stack, yet each free from danger of self-siphonage because neither waste pipe from the trap dips low enough before entering the stack to form the long leg of a siphon. Whether there would be danger of siphonage from other fixtures discharging into the stack at higher levels would depend on the relative size of the stack, and the greatest discharge of water that would enter it at the higher level, and would be within reasonable limits independent of the distance of the trap from the stack. Indeed, the pull on the water in a trap is greater the nearer the trap is to the stack. It would be perfectly safe to set a closet four to five feet from a stack, and a small fixture-trap six to seven feet from the stack.

BACK-VENTING TRAPS.—Siphon traps, unprotected from siphonage by vent pipes, offer no security whatsoever against the passage of drain air into a building; therefore, any system of plumbing in which siphon traps are used should be properly vented or back-vented. A vent pipe not only protects the seal of a trap from siphonage, but also relieves the seal from back pressure and affords ventilation for the short length of waste pipe from the soil or waste stack to the fixture trap. This last consideration is of but small importance, however, because the air in branch waste pipes is changed each time the fixture it connects to is flushed. Furthermore, the air in the short lengths is kept fairly pure by diffusion with the air in the soil or waste stack.

VENT CONNECTIONS TO TRAPS.—An old method of back-venting fixture traps was to connect the vent pipe to the crown of the trap, as at *a*, Fig. 52. A better practice, however, is to connect the vent pipe to the waste pipe a few inches away from the trap, as at *b*, but not far enough away so the waste pipe would form the long leg of a siphon. When a vent pipe is connected to the crown of a trap it increases

the rate of evaporation of water from the trap; also, when much grease is emptied into a fixture the vent pipe, if connected to the crown, is liable to become entirely stopped up with the grease.*

EXAMPLE OF BACK-VENTING.—An example of back-venting the fixture traps in an ordinary bath room is shown in Fig. 53. The chief conditions to be here noted are: (1) The height of the vent pipe where it enters the vent stack. It is kept above the outlet to the highest fixture in the group so that the vent pipe cannot be used as a waste pipe by any of the fixtures in case the waste pipe becomes obstructed; (2) the vent pipe slopes from the vent stack toward the fixture traps to discharge into the waste pipes all water of condensation or any sewage that might back up in the vent pipes, should the waste pipe be obstructed; (3) the distance away away from the seal of traps at which the vent pipes connect to the waste pipes. It should be further observed that the vent to the water closet does not connect to the closet trap above the floor, but to the lead bend below the floor, as a permanent and secure joint cannot be made to an earthenware closet trap, owing to the shrinkage of the floor joists which would break the vent horn of the closet. If the closet is either of the siphon-jet or the siphon-action type, no vent will be necessary, providing fixtures do not discharge into the soil stack at a higher level, because siphonic action is necessary to operate either type of closet,

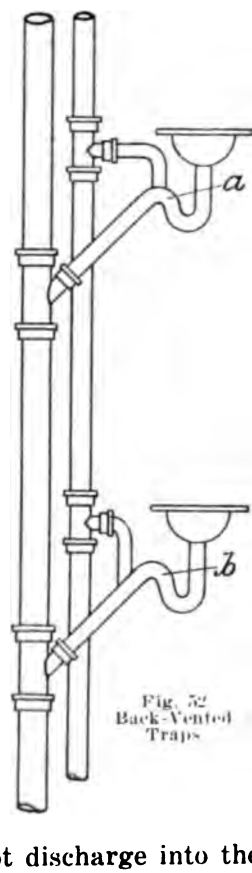


Fig. 52
Back-Vented
Traps

*Inspector W. J. Freaney, of St. Paul, in an examination of vent pipes from fixture traps, found that out of twenty-three traps from kitchen sinks, twelve were completely obstructed with grease, ten partially obstructed, and only one perfectly clear. The latter, however, had been regularly inspected and cleaned.

and the after-wash from the flush cistern is depended upon to again seal the trap. Main-drain traps, leader traps, yard and area traps and stall drain traps do not require back-venting, because if they are emptied by siphonage their seals are soon replaced by drippings.

CONNECTING SEVERAL FIXTURES TO ONE TRAP.—When a number of wash basins are grouped together in a wash room of a factory, hotel, or other institution it is common practice to connect the waste pipes from all the basins to one trap. A better practice, however, is to trap each basin separately. When but one trap is used in an installation of this kind, it leaves untrapped a large stretch of pipe, which in time becomes foul and emits disagreeable odors, that are carried into the room by local currents of air circulating in through the pipe at one basin connection and out at another basin.

KITCHEN SINKS AND LAUNDRY TRAYS.—There are conditions under which the use of one trap for two or more fixtures is permissible. In apartment buildings, where laundry trays adjoin the kitchen sink, and there is a possibility that for long periods of time the trays may not be used, it not only is permissible but perhaps better to connect the waste pipe from the trays to the house side of the sink trap below the water level. By this arrangement a permanent seal is assured the trays whether they are used or not. The waste pipes from the trays, however, should be offset above the water level in the trap so the waste pipe will not stand full of water.

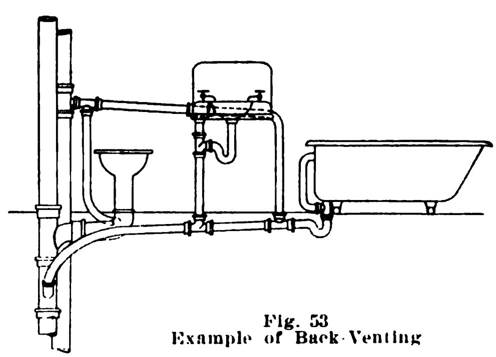


Fig. 53
Example of Back-Venting

The waste pipe from the kitchen sink should never connect to a laundry-tray trap, as that would leave untrapped a greater stretch of pipe than when the conditions are

reversed; besides, the untrapped pipe would soon foul from the greasy sink water passing through it, and local circulation would set up from the tub waste through the tray waste, carrying the odors into the kitchen.

CLOTHES WASHING MACHINES.—In these days of machines and machine labor, no private laundry is complete without a power operated machine washer for the laundering of the household linen. Machines designed for this purpose may now be had which can be supplied with hot and cold water, and connected to the drainage system. These machines are made for motors which are electrically operated, or with motors which are operated with water supplied from the city water mains. When water power is to be used, however, there must be an available pressure at the motor of at least 30 pounds per square inch, with fair volume, or the motor will not operate satisfactorily.

In addition to a washing machine, a gas-heated or electrically-heated mangle will be found a valuable fixture in the laundry of every good-sized home. On the mangle most of the household ironing can be done, outside of the more particular pieces which are best done by hand, and between the washing machine and the mangle, the hardest and heaviest of household work is done without an effort.

CHAPTER X

BLOW-OFF TANKS AND REFRIGERATOR WASTES

Blow-Off Tanks for Boilers

EFFECT OF STEAM IN DRAINAGE SYSTEMS.—High pressure steam boilers should never blow off or exhaust directly into a drainage system, but should first pass through a cooling tank that will condense the steam and cool the water to a moderate temperature. When live steam is discharged directly into a drainage system the steam heats the water in traps, causing it to vaporize and emit a disagreeable odor within the building. Also, if the system is constructed of cast iron with lead calked joints the expansion and contraction of the lines will work the lead calking out of the hubs and cause the joints to leak.

TYPE OF BLOW-OFF TANKS.—A blow-off tank and connections are shown in Fig. 54. Water enters the condensing tank from the boiler through the pipe *a*. When released from pressure, some of the water instantly flashes into steam and escapes to the atmosphere through the vapor pipe, *b*. Hot water entering the tank causes cold water from the bottom of the tank to overflow through the pipe *c*, to the house sewer outside of the main drain trap. An equalizing pipe, *d*, admits air to the overflow pipe and thus prevents the water being siphoned out of the tank.

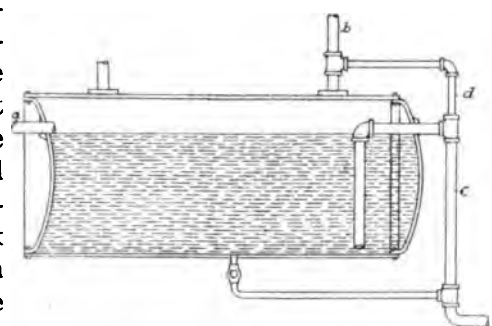


Fig. 54
Blow-Off Tank

Where gravity discharge cannot be had, boilers may be allowed to blow off into a sump, and the water when it has

cooled pumped out with a submerged centrifugal pump of the vertical type, direct connected to a motor. A vent from the sump to the atmosphere should be provided.

SIZE OF BLOW-OFF TANKS.—A blow-off tank should be large enough to hold one gauge of water from the steam boiler. In blowing off a steam boiler, one gauge of water is the most that should be blown off at one time, and if the tank is large enough to hold that quantity it will be sufficiently large for all purposes. The size of tank required can be found by multiplying the length of the steam boiler in feet by the diameter in feet and multiplying the product by one-third (4 inches being considered the depth of one gauge of water). This product will be the capacity in cubic feet of the tank required.

EXAMPLE—What capacity blow-off tank will be required for a steam boiler 18 feet long and 5 feet in diameter?

SOLUTION—$18 \times 5 \times \frac{1}{3} = 30$ cubic feet, and $30 \times 7.5 = 225$ gallons capacity.

Stock sizes of blow-off tanks can be found in Table XIX.

TABLE XIX. Dimensions and Capacities of Blow-Off Tanks

Capacity Cubic Feet	Capacity Gallons	Length in Feet	Diam. in Inches	Approximate Weight
33	250	6	30	500
43	325	8	30	650
53	400	10	30	800
63	475	8	36	800
80	600	10	36	950
90	700	12	36	1100
133	1000	12	42	1400
166	1250	12	48	1700

When ordering blow-off tanks the order should be accompanied by a sketch showing the location and size of the several outlets.

When several boilers are connected in battery one blow-off tank will suffice for all, provided sufficient time is allowed between blowing off the several boilers for the water in the tank to cool, or if provision is made for cooling the hot water with cold water coils.

SIZE OF TANK OUTLETS.—Blow-off outlets to steam boilers are seldom over two inches in diameter, therefore the inlet to blow-off tanks need not be over 2 inches, iron-pipe size. The outlet, however, should be 2½ or 3 inches in diameter, so the water will enter the sewer at a slow velocity. The vapor pipe should be 2 inches in diameter, and if it extends over 100 feet should be 2½ inches in diameter.

Drips from high-pressure plants do not require a condensing tank but may connect to an atmospheric steam trap discharging into the house sewer outside of the main drain trap.

Blow-offs from low-pressure boilers need not pass through either a condensing tank or a steam trap, but may discharge freely into the house sewer outside of the main drain trap, if there is one, or in the house sewer where there is no main drain trap.

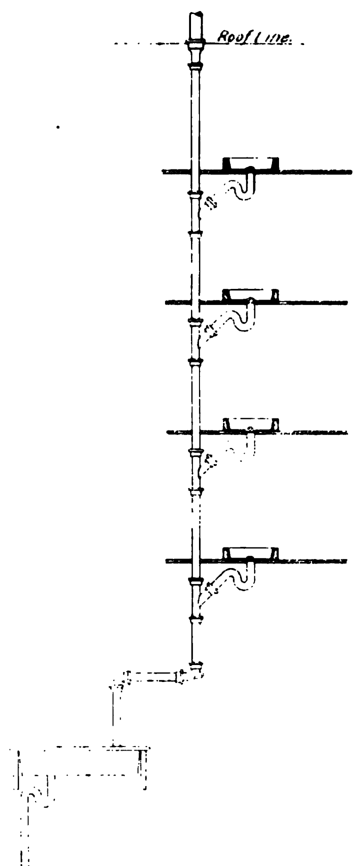


Fig. 55
Refrigerator Waste Pipes

Refrigerator Wastes

SYSTEM OF PIPING.—In apartment houses, of the better class, refrigerator waste pipes are usually installed to carry off the drip from ice boxes in the several apartments. Fig. 55 shows the general system of piping for refrigerator wastes. The main refrigerator stack does not connect to the drainage system but discharges into a trap-

ped and water-supplied sink in the cellar or basement, and should open to the atmosphere above the roof.

Galvanized wrought iron pipe should be used for refrigerator wastes, and the ends should be well reamed to remove the burr formed by cutting the pipe. Fittings should be of the recessed drainage type, well galvanized both inside and out. Full Y fittings should be used for branch connections to the various refrigerator safes, and a Y branch with clean-out plug should be used at all changes of direction of the horizontal mains.

The main waste pipe from refrigerators should never be less than $1\frac{1}{4}$ inches diameter, and seldom need be over $1\frac{1}{2}$ inches. Branch connections to the refrigerator safes, also refrigerator wastes in private houses, need not be over 1 inch in diameter.

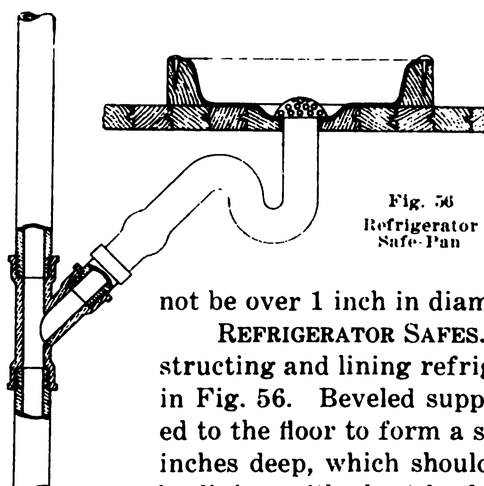


Fig. 56 Refrigerator Safe-Pan

REFRIGERATOR SAFES.—The manner of constructing and lining refrigerator safes is shown in Fig. 56. Beveled supporting strips are nailed to the floor to form a shallow pan, about $1\frac{1}{2}$ inches deep, which should be made water-tight by lining with sheet lead or sheet copper. The outlet from the pan should be countersunk, and the opening protected by a removable strainer secured in place by a cross bar. Brass, aluminum, galvanized cast-iron refrigerator safes, also earthenware safes with couplings, can now be had. Any of these materials is better than lead safe pans.

TRAPPING REFRIGERATOR SAFES.—Each refrigerator safe should be separately and properly trapped and connected to the main refrigerator waste stack. The best type of trap to use for this purpose is a plain siphon trap of $\frac{3}{4}$ S pattern. The angle of the outlet leg of a $\frac{3}{4}$ S trap permits the slime that accumulates in the waste pipe from an ice

box to slide into the vertical stack and thence to the sink. It is not necessary to back-vent refrigerator waste traps, nor use non-siphon traps, because a flush of water of sufficient volume to siphon a trap is never discharged into a refrigerator waste; even if it were, the constant drip from the ice box would soon seal the trap again.

In private houses the refrigerator waste need only extend from the refrigerator safe to the drip sink, where it should terminate with a light swing-check valve to prevent cellar air entering the living rooms through the waste pipe. No trap is required where only one refrigerator connects to a waste, nor is it necessary in such cases to extend the pipe through the roof.

CHAPTER XI
MECHANICAL DISCHARGE SYSTEMS

SUB-SEWER SYSTEMS.—Mechanical ejectment of sewage is resorted to in cases where the street sewer is above the level of the area to be drained. This condition, however, is only found in the sub-basement floors of tall city buildings, underground public toilet rooms and underground passenger stations.

A system of mechanical ejectment consists of a gravity drainage system to a receiving tank or sump located in a water-tight pit at the lowest part of the drainage system, and a pump or compressed air ejector to raise the sewage and discharge it into the street sewer.

Systems of piping for sub-sewer drainage are the same as for gravity discharge systems. In cities where main drain traps are required, the sub-sewer system should have a main drain trap and fresh air inlet, and the fixture stacks should extend through the roof. In short, a sub-sewer system is exactly the same as a gravity system, except the mechanical apparatus for elevating the sewage. A separate vent pipe should extend from the tank or sump to above the roof.

CENTRIFUGAL PUMP EJECTORS.—There are three types of apparatus used to raise sewage to the street sewer, each of which has certain features to recommend it. When the volume of the sewage to be removed is large and the height to be raised is small, a centrifugal pump will give very satisfactory results. This type of pump can be driven by belting or may be operated by an electric motor direct-connected to the pump shaft. By means of a float and an automatic switch an electric-driven pump can be made to operate automatically, starting when the tank is filled with sewage and stopping when it is empty. The manner of installing a centrifugal pump and tank is shown in Fig. 57. With this type of ejector an ordinary steel tank is used that may be either open or closed. The pump should be set below the level of the receiving tank, so it will remain full of water

and not require priming. If placed above the level of the tank a primer will be necessary to start the pump, and this so complicates the apparatus that it is more difficult to fit up to work automatically. Where the sewage is coarse and full of solid matter, as is likely to be the case in slaughter houses or factories, a centrifugal pump will give the best results. It has few working parts to get out of order, and no parts that can choke up and thus render the pump temporarily useless; for any substance, even coal or bricks, that passes through the inlet port can easily be discharged from

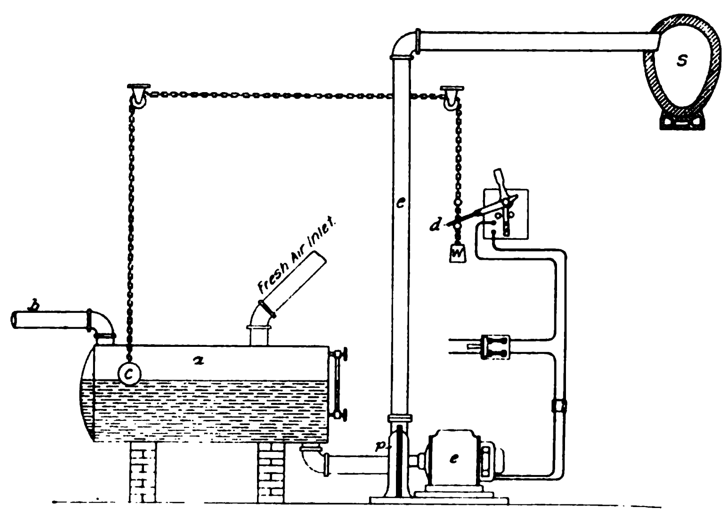


Fig. 57
Centrifugal Pump Sewage Lift

the outlet. Speed is an important factor in the capacity of centrifugal pumps; increasing the speed increases the capacity and also the height to which it will raise sewage, while decreasing the speed will reduce considerably the volume of sewage and the height it will be raised. Direct-connected, electrically-operated, vertical type of submerged centrifugal pumps are best for the purpose.

The operation of the apparatus shown in Fig. 57 is as follows: Sewage enters the sump *a* through the house drain *b;* as the tank fills, the sewage raises the float *c,* and thus by means of the chain, pulleys and weight *w,* depresses

the lever *d* until it reaches a certain point when contact is made that completes an electric circuit connected to the electric motor *e*. The current thus automatically turned on operates the electric motor that drives the pump *p*, and thus ejects the sewage from the tank through the discharge pipe to the sewer *s*. As the water line in the tank lowers, the float falls until it reaches a certain level near the bottom, when the automatic switch opens, thus breaking the electric circuit and stopping the pump.

PISTON-PUMP EJECTORS.—When the volume of sewage to be raised is small or the height it is to be elevated is great, the piston type of pump will give the best results. The sewage should be screened, however, before entering the suction pipe of this type of pump, to prevent the entrance of anything that might have been carelessly introduced into the drainage system which might interfere with or injure the working parts of the pump. Piston pumps are suitable only for comparatively clear sewage, and should not be used where coarse, insoluble materials are discharged into the drain or where chemicals are discharged that might cut the valve seats of a pump.

Piston pumps may be electrically driven or operated by steam, and may be made to operate automatically or to be started and stopped by an attendant. The manner of installing a piston pump ejector is similar to the manner of installing a centrifugal pump ejector, with the single exception that a piston pump may be located at any convenient point not over twenty-eight feet above the level of the sump. When steam is the motive power, the pump may be connected up to work automatically in the same manner as a feed-water pump and receiver.

COMPRESSED-AIR EJECTORS.—Air ejectors are now more generally used for sewage ejectment than any other type of apparatus. They are automatic and almost noiseless in operation, are perfectly odorless, and have but few working parts than can get out of order. A type of compressed air ejector known as the Shone, is illustrated in Fig. 58. Sewage flows into the chamber *a* through the house drain *b*. As the chamber fills with sewage it raises

the bucket *c* until it reaches a certain level, when by means of the rod *d*, it opens valve *e*, thus admitting compressed air to chamber *a*. The pressure of air closes the check valve *f* through which sewage entered the chamber and opens check valve *g* through which it forces the contents of the sump into the street sewer. As the sewage level in the sump falls, the bucket float, which remains full of sewage, lowers with the contents until it reaches a point near the bottom of the chamber, when it closes the air valve, thus

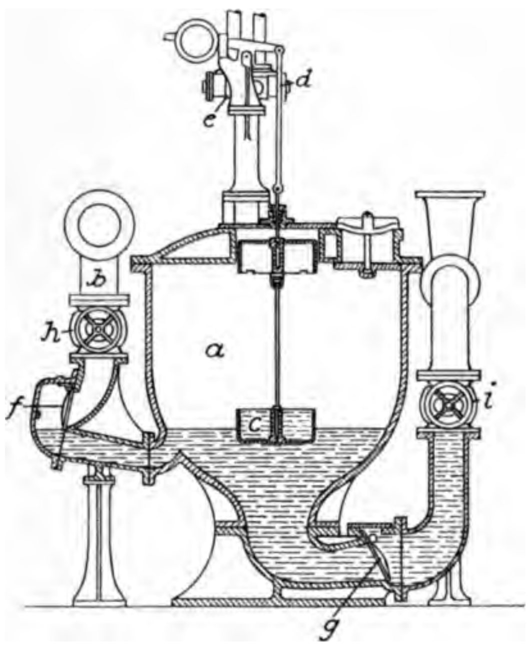


Fig. 58
Compressed Air Sewage Ejector

shutting off the supply of compressed air, and at the same time opening a vent through which the confined air can escape to a vent stack. Valve *h* is placed in the house drain pipe to the tank, and valve *i* in the discharge pipe from the tank, so that the ejector may be cut out of service at any time.

Sewage ejectment apparatus should always be installed in duplicate so that either apparatus may be cut out for

cleaning or repairs without interrupting the drainage service. The manner of installing a duplicate compressed air apparatus is shown in Fig. 59.

The size of sump tanks for sewage ejectment depends upon the frequency with which they are to be emptied and the probable amount of sewage to be taken care of. When operated automatically they need only be large enough to hold an hour's storage of sewage, during the hour of maximum flow. The process of emptying occupies only a few minutes, when the tank is ready for service again. If the apparatus is not to be operated automatically, storage

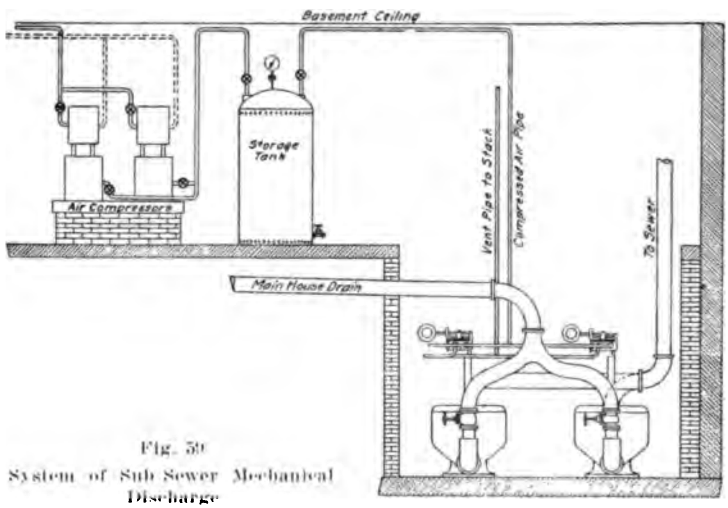


Fig. 59
System of Sub Sewer Mechanical Discharge

capacity for twenty-four hours should be provided. In estimating the quantity of sewage from basement floors of different classes of buildings, greater per capita allowance should be made for the basement and sub-basement floors of hotels and like institutions than from other classes of buildings.

Storage tanks for compressed air are usually made of galvanized sheet iron similar to those used for the storage of hot water. They should be equal in size to the cubical capacity of the sumps they are to discharge. When made of such a size, at least two pounds pressure of air should

be maintained as working pressure for each foot in height the sewage must be raised; with greater pressure a more speedy ejectment is obtained. To operate satisfactorily with lifts of less than 7 feet, at least 15 pounds pressure of air should be maintained; 30 to 40 pounds is the pressure the average sewage ejectment plant operates under.

Sub-Soil Drainage

OBJECT OF SUB-SOIL DRAINAGE.—In localities where the ground water is high or where impervious strata of clay or rock causes seepage to dampen the foundation walls or wet the cellar floor, sub-soil drains are resorted to. The manner of laying a sub-soil drain is shown in Fig 60. A line of field tile is laid around the outside of the foundation wall below the level of the foundation footings or the cellar floor. The pipes are laid with open joints which are covered with tile collars, pieces of tar paper, excelsior, bagging or some other coarse material that will keep out dirt until the earth settles and packs into shape. The drain should be covered for a depth of 12 to 18 inches with crushed stone and the trench then filled to within a foot of the top with loose porous materials through which water will easily percolate to the drain. The top dressing for the trench may be any kind of good loamy soil suitable for a lawn.

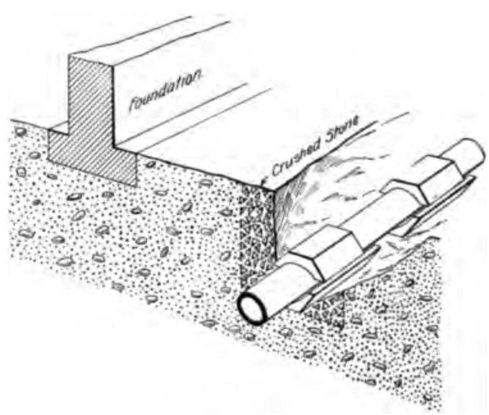


Fig. 60
Sub-Soil Drain

DISPOSAL OF SUB-SOIL WATER.—When the street sewer is provided with a sub-sewer drain, as is usually the case in localities where the ground water is high, the proper place to dispose of sub-soil water is in the sub-sewer drain. Most

brick sewers, Fig. 61, are provided with a tile invert, *a*, the channels of which serve as a sub-sewer drain; and pipe sewers in wet districts usually have a field pipe sub-sewer drain. When, however, there is no sub-sewer drain the sub-soil water can discharge into the house sewer through a water seal and tide water trap. Sometimes a sub-soil drain is so far below the sewer level that sub-soil water cannot discharge into it by gravity. When such is the case, it can be gathered in a sump and discharged to the street sewer by a submerged type centrifugal pump. If, however, the volume of water is too small, and the distance it is to be raised too short to warrant installing a sewage ejectment apparatus, an automatic cellar drainer, may be used. This type of apparatus may be operated by water or steam, although city water is generally used. It cannot be operated by air pressure. It operates on the principle of an ejector. The drainer is placed in a pit below the level of the cellar floor, into which the sub-soil water drains. When the water reaches a certain level it raises the float; this turns city water on to the apparatus, and as the water flows through the ejector nozzle, it entrains water from the pit which mixes with the city water in the pipe, and together they are discharged into a water-supplied sink at some convenient point. When the water is discharged from the pit the float falls again, thus shutting off the flow of the city water until the pit fills again. This method, however, is too expensive to use for discharging large quantities of water and is not economically effective for a greater lift than 12 feet. The height to which water can be raised by a cellar drainer depends upon the available water pressure; with a pressure of 100 pounds, water can be raised 25 feet, but the amount of city water required to raise water that height makes the method too expensive for handling large quantities of water. At least four pounds

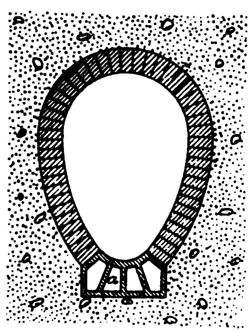


Fig. 61
Tile Invert of Brick Sewer

of pressure are required for each foot of lift, with a minimum pressure of at least 10 pounds.

The possibility of using water from automatic cellar drainers for flushing fixtures should not be overlooked. Ordinarily, the water discharged by a water drainer is perfectly clear, being nothing more or less than the ordinary ground water of the locality. To this must be added the city water used for operating the drainer, which, of course, is also clear and suitable for flushing purposes.

Where there are basement closets or urinals to be flushed, or water can be used on an overshot water wheel for operating mechanical apparatus, as is done with some domestic ice-making machines, the drainage water can be used for this purpose, thereby making the operation of the drainer free of cost.

The lower the lift of the drainage water, the less water will be required for the purpose, so, instead of a water supplied sink, ordinarily the water can be discharged into a floor drain, or yard drain if the climate is not too cold.

An automatic cellar drainer, or a mechanical discharge system of any kind, ought never to be used, of course, when it is possible to take care of the drainage water by gravity. It is only when the surface to be drained is below the level of the street sewer or other place of sewage disposal or drainage water disposal, that they are permissible.

It is not advisable to connect an automatic cellar drainer direct to a drainage system, for, besides the possibility of sewer air finding its way into the house through the connection during dry weather, there is the additional possibility of water running continuously to waste through the cellar drainer should it get out of order without any one being aware of the fact. Both sanitary and economic reasons, therefore, require that a cellar drainer discharge into a tank, sink, floor drain, or other receptacle where the water can be seen running when the apparatus is in operation.

Drainers will work satisfactorily with 4 pounds pressure to one foot in lift. To raise water:

1 foot	requires	4	to	5 lbs.	pressure
2 "	"	8	"	10 "	"
3 "	"	12	"	15 "	"
4 "	"	16	"	20 "	"
5 "	"	20	"	25 "	"

and so on in proportion up to 12 feet in height. Drainers do not satisfactorily lift water more than 12 feet.

PART II

WATER SUPPLY SYSTEMS

COLD WATER SUPPLY

CHAPTER XII

PROPERTIES OF WATER

GENERAL DATA ABOUT WATER.—Pure water is a colorless, tasteless, odorless, limpid fluid, that is practically incompressible; for each atmosphere of pressure it sustains it is compressed only 47½ millionths of its bulk. Its compressibility is from .000040 to .000051 for one atmosphere, decreasing with increasing temperature. For each foot of pressure, distilled water will be diminished in volume .0000015 to .0000013 of its bulk. Water is so nearly incompressible that even at a depth of a mile a cubic foot of water will weigh only about half a pound more than at the surface. It is a chemical combination of oxygen and hydrogen in the proportions of 88.9 parts by weight of oxygen to 11.1 parts of hydrogen, or 1 volume of oxygen to 2 volumes of hydrogen. Its weight varies with its temperature; at 62° F., which is taken as the average temperature, 1 cubic foot weighs 62.355 pounds.

For ordinary calculations, the weight is taken in round numbers at 62.5 pounds per cubic foot: when greater precision is required, it is taken at 62.4 pounds per cubic foot, its weight at 52.3° F.

The gallon is the unit of measure for water. One gallon of water measures .134 cubic feet, contains 231 cubic inches, and at 62° F. weighs about 8⅓ pounds. The United States gallon differs from the British or Imperial gallon, with which it should not be confused. A comparison of the American and Imperial gallon may be found in Table XX.

TABLE XX. Weight and Capacity of Different Standard Gallons of Water

	Cubic Inches in a Gallon	Weight of a Gallon in Pounds	Gallons in a Cubic Foot	Grains in a Gallon at 60° F.	Weight of a Cubic Foot of Water, English Standard Pounds Avoirdupois
Imperial or English	277.274	10.00	6.232102	70,465	62.321
United States	231	8.33448	7.480519	58,327	62.321
New York	221.81718	8.00	7.901285	58,538	62.321

NOTABLE TEMPERATURE OF WATER.—There are four notable temperatures for water, viz.:

Fahr.		Cent.	
32°	or	0°	= the freezing point under one atmosphere;
39.1°	or	4	= the point of maximum density;
62°	or	16.66°	= the British standard temperature;
212°	or	100°	= the boiling point under one atmosphere.

The weight of one cubic foot of water at the four notable temperatures may be found in Table XXI.

TABLE XXI. Weight of Water

At 32° F.	62.418 pounds
At 39.1°	62.425 pounds
At 62° (standard temperature)	62.355 pounds
At 212°	59.640 pounds

The following factors are useful for changing given quantities of water from one denomination to another:

1 cubic inch of water weighs .577 ounce or .03608 pound.

1 cubic foot contains 1,728 cubic inches.

1 cubic foot contains 7.485 United States gallons, which, in ordinary calculations, is taken as 7.5 gallons.

Cubic feet	× 62.5 = pounds
Pounds	÷ 62.5 = cubic feet
Gallons	× 8.3 = pounds
Pounds	÷ 8.3 = gallons
Cubic feet	× 7.5 = gallons
Gallons	÷ 7.5 = cubic feet

SNOW AND ICE.—Water expands in freezing about one-twelfth of its bulk, or from 1000 to 1083. Sea water freezes at 27° F. The ice is fresh.

Specific gravity of ice,	0.916	Ure.
Specific gravity of ice,	0.918	Miller.
Specific gravity of ice,	0.9184	Abel & Bloxam.

1595 cubic inches of water will expand in freezing to one cubic foot of ice. One pound of ice at 32° F. has a volume of .0174 cubic foot, 30,067 cubic inches.

	Lbs.	
One cubic foot of ice weighs	57.135	Ure:
One cubic foot of ice weighs	57.260	Miller.
One cubic foot of ice weighs	58.632	Abel & Bloxam.

Relative volume of ice to water at 32° F., 1.0855. At high pressure the melting point of ice is lower than 32°, being at the rate of .0133° for each additional atmospheric pressure. The specific heat of ice is .504, that of water at standard temperature being 1.

Sound ice, two inches thick, will bear the weight of the average man; four inches, a man on horseback; six inches, cattle and teams with light loads; eight inches, teams with heavy loads; ten inches, will sustain a pressure of 1000 pounds per square foot. The ice must be sound, free from shakes, cracks and frozen snow.

Snow is 10 to 12 times lighter than an equal volume of water; that is, one inch of rainfall will make from 10 to 12 inches of good, clear, crystalline snow. A cubic foot of fresh snow, according to the humidity of the atmosphere, will weigh from five to twelve pounds. A cubic foot of snow moistened and compacted will weigh fifteen to fifty pounds.

Molesworth gives the following relating to snow:

Specific gravity is	0.0833	
One cubic inch of snow,	= 0.003	pound.
One cubic foot of snow,	= 5.2	pound.
One pound of snow,	= 332.6	cubic inches.
One pound of snow,	= 0.1923	cubic foot.
One inch snow fall,	= 0.433	lbs. per sq. ft.

Water in freezing always expands. If it is so confined that expansion is impossible, it remains liquid even at temperatures far below the freezing point; but the instant pressure is removed, the water crystallizes into solid ice. As there is a constant effort on the part of the water to form ice and as a considerable pressure is needed to counterbalance its expansive power, the lower the temperature the greater this pressure becomes. At a temperature of 30 degrees Fahrenheit, just two degrees below the freezing point, the pressure is equal to 138 tons per square foot. It will be seen, then, that when water freezes in a pipe or closed vessel, it exerts a pressure of approximately one ton per square inch; and this is the destructive agency which bursts pipe and tanks.

CLASSIFICATION OF WATER.—Waters for domestic uses may be divided into two general classes; *hard waters* and *soft waters*. Hard waters can be either *permanently hard*, *temporarily hard*, or both *permanently* and *temporarily hard*. By hardness of water is meant its soap destroying or neutralizing power, which is due to the presence of carbonates or sulphates of lime or magnesia. A large degree of permanent hardness indicates a bad water. Permanently hard waters contain sulphates of lime or magnesia in solution; temporarily hard waters contain carbonates of lime or magnesia in solution, and both permanently and temporarily hard waters contain sulphates and carbonates of lime or magnesia in solution.

Hardness of water is measured in degrees (Clark-Wanklyn), and each degree of hardness corresponds to one grain of carbonate of lime or magnesia to one English gallon of water. Hardness expressed in parts per 100,000 can be converted to Clark's scale by multiplying the hardness by .7. The reason for this is Clark's scale gives the results in grains per English gallon, and there are 70,000 grains in an English or imperial gallon.

EXAMPLE—How many degrees hardness (Clark) in water that is 20 parts hard per 100,000?

SOLUTION—$.7 \times 20 = 14$ degrees Clark.—Ans.

Conversely, hardness expressed in degrees (Clark) can be changed to parts per 100,000 by dividing the degrees of hardness by .7.

EXAMPLE—How many parts of hardness per 100,000 in water that contains 14 degrees of hardness?

SOLUTION—$14 \div .7 = 20$ parts per 100,000.—Ans.

Hardness expressed in parts per 100,000 can be changed to grains per United States gallon by multiplying the hardness by .584. The reason for this is that a United States gallon contains approximately 58,400 grains. Conversely, hardness expressed in grains per United States gallon can be changed to parts per 100,000 by dividing the grains of hardness by .584, or, where great refinement of calculation is not required, by the constant .6.

EXAMPLE—How many grains of hardness per United States gallon in water that contains 20 parts per 100,000?

SOLUTION—$20 \times .584 = 11.68$ grains per gallon.—Ans.

EXAMPLE—How many parts of hardness per 100,000 in water that contains 11.68 grains per United States gallon?

SOLUTION—$11.68 \div .584 = 20$ parts per 100,000.—Ans.

The manner of determining the degree of hardness in water is as follows: Seventy cubic centimeters* of water are placed in a clean glass bottle large enough to hold two or three times that quantity. A clear solution of soap of standard strength is then added, a little at a time, from a graduated tube, and the mixture briskly shaken. On some waters a slight lather will form at first, which will quickly disappear, or if the water is very hard a curd will form. More soap should then be added, shaking the bottle after each addition until the lather formed is sufficiently permanent to stand for five minutes. The number of cubic centimeters of soap solution added, less one, indicates the hardness of the water in degrees. The one cubic centimeter is deducted because even distilled water requires a small quantity of soap to make it lather.

STANDARD SOAP SOLUTION.—Standard soap solution is of such strength that one cubic centimeter contains sufficient

*Table for converting American and metric measures in appendix.

soap to exactly neutralize one millogram of dissolved carbonate of lime. It is made by mixing half an ounce of finely shredded castile, or mottled soap, with two pints of methylated spirits and one pint of distilled water. The mixture should be kept at ordinary temperature, and allowed to stand for a few hours, occasionally shaking, then passed through a filter of blotting paper. Before using the solution it should be tested by means of water of known hardness. In case the solution is too strong, it should be diluted with spirits and water until the strength is just right.

Soft water contains no mineral impurities. Rain water is the purest kind of natural soft water.

The character of water, its corresponding degree of hardness and chemical substance causing the hardness, rated as equivalent to grains carbonate of lime, may be found in Table XXII.

TABLE XXII. Hardness of Waters

Character of the Water	Degree of Hardness (Clark-Wanklyn)	Hardness Parts per 100,000	Grains Carbonate of Lime in 1 English Gallon	Grains Carbonate of Lime in 1 United States Gallon
Very soft	1°	1.4	1	.82
Soft	2°	2.8	2	1.65
Softness decreasing	3°	4.3	3	2.51
Moderately soft	6°	8.6	6	5.
Moderately hard	8°	11.4	8	6.65
Hard	9°	13.	9	7.6
Very hard	12°	17	12	9.9
Excessively hard	16°	23.	16	13.4
Intolerably hard above this point	17°	24.	17	14.

Even the softest of water contains a small proportion of lime or magnesia as a rule, and it may be assumed that the softest of water is at least one degree hard.

In limestone regions, such as the upper Mississippi Valley, water of 10 degrees hardness is not uncommon, while some of the water pumped from the chalk beneath the City of London, England, is as hard as 22 degrees Clark.

CHAPTER XIII

SOLVENT POWER OF WATER

RANGE OF SOLVENCY.—Water is an almost universal solvent. Its range is greater than any other known liquid. It dissolves to a greater or less extent all minerals, and many metals with which it is brought in contact. As a rule, the solvent power of water increases with its temperature, but for common salts the solvent power is nearly constant at all temperatures. Lime salts are more soluble in cold than in hot waters, and it is due to this latter fact that incrustation of water backs takes place in regions when the water supply is hard. In percolating through the earth the water dissolves carbonates or sulphates of lime or magnesia from lime rocks, until the water reaches the point of saturation; then, when subjected to heat in a water back or heater, the point of saturation of the water is lowered, thus liberating some of the lime or magnesia which settles upon and becomes baked to the walls of the water back or heater.

The proportion of mineral that can be dissolved by a given quantity of water depends upon the nature of the mineral, the kind of water and its temperature. The relation between soluble minerals and water is absolute. That is, at a given temperature a certain quantity of water will dissolve a definite quantity of mineral salts; if a quantity greater than this be added to the water, the amount in excess will settle to the bottom of the vessel. The water is then saturated, and the mixture is a saturated solution. By increasing or decreasing the temperature of the water, as the nature of the mineral requires, a greater quantity can be dissolved.

The greatest quantity of various substances in common use that can be dissolved by one imperial gallon of water can be found in Table XXIII. The figures do not indicate

the weight of chemical contained in a gollon of saturated solution.

EFFECT OF WATERS UPON METALS.—The solvent power of water is not confined to minerals alone, but, under favorable conditions, will attack and dissolve metal from water pipes or from other metallic surfaces with which it comes in contact. The energy with which water attacks metals

TABLE XXIII. Solubility of Water

(COLLETT)

One Imperial Gallon of Pure Water can Dissolve of Substance	At 60 Degrees Fahrenheit	At 212 Degrees Fahrenheit
Alum (potash alum)	0.95 pounds	35.7 pounds
Aluminum sulphate	3.3 pounds	8.9 pounds
Ammonium oxalate	0.45 pounds	4.08 pounds
Barium chloride	3.5 pounds	6.0 pounds
Barium hydrate	0.5 pounds	1.0 pounds
*Calcium carbonate	2.5 grains	1.5 grains
Calcium chloride	40.0 pounds	Unlimited
Calcium	93.0 grains	53.6 grains
Calcium nitrate	40.0 pounds	Unlimited
Calcium oxide (lime)	70.0 grains	40.5 grains
†Calcium sulphate	161.0 grains	152.0 grains
Ferrous sulphate	2.0 pounds	17.8 pounds
*Magnesium carbonate	Doubtful	1.5 grains
‡Magnesium chloride	20.0 pounds	40.0 pounds
Magnesium hydrate	2.0 grains	2.0 grains
Magnesium oxide	1.4 grains	1.4 grains
Magnesium sulphate	3.0 pounds	13.0 pounds
Sodium biborate (borax)	0.4 pounds	5.5 pounds
Sodium carbonate (dry)	1.2 pounds	4.5 pounds
Sodium carbonate (crystals)	4.1 pounds	14.0 pounds
Sodium chloride	3.5 pounds	4.0 pounds
Sodium hydrate	6.1 pounds	Unlimited
Sodium hyposulphite	5.0 pounds	20.0 pounds
Sodium phosphate	1.2 pounds	
Sodium sulphite	2.5 pounds	10.0 pounds
Sodium sulphate	1 1 pounds	4.2 pounds

*Insoluble at about 280 degrees Fahrenheit. †Decomposes at boiler temperature in presence of alkaline earths or iron. ‡Insoluble at 302 degrees Fahrenheit, equal to 70 lbs. steam pressure.

depends largely upon the character of the water, the nature of the metal and the amount of free carbonic acid contained in the water. As a rule, soft water attacks and dissolves metals to a greater extent than will hard water, although there are exceptional cases where permanently hard waters

have been known to attack lead pipes with an energy equal to that of soft waters. It is not sufficient that water be soft to cause it to attack metals; there must also be present in the water some oxygen and carbonic acid, either free or in solution. If either the oxygen or the carbonic acid are

TABLE XXIV. Lead Found in Drinking Water

LIST OF CITIES AND TOWNS WITH MAXIMUM AMOUNTS OF LEAD FOUND IN SAMPLES OF WATER TAKEN DURING ORDINARY USE AND AFTER STANDING IN THE PIPE

LOCALITY	Lead Parts per 100,000 (.05 parts of lead per 100,000, dangerous)	
	During Ordinary Use	After Standing in Pipe
Amesbury	.0029	0.0043
Andover	.0171	0.0571
Attleborough	.1714	0.1371
Beverly	.0257	0.0314
Bridgewater	.0086	0.0171
Brookline	.0114	0.0286
Cambridge	.0086	0.0114
Cohasset	.0086	0.0086
Dedham	.0100	0.0200
Franklin	.0286	0.1143
Grafton	.0229	0.0457
Hyde Park (old wells)	.0457	0.4571
Hyde Park (new wells)	.0200	0.0457
Lawrence	.0371	0.1829
Lowell (boulvevard wells)	.0800	0.4000
Lowell (cook and hydraulic wells)	.5143	0.4643
Marblehead	.0086	0.0143
Metropolitan supply	.0400	0.1371
Middleborough	.3429	1.1429
Needham	.0171	0.0429
Newton	.0714	0.1714
North Attleborough	.0071	0.0329
Norwood	.0043	0.1371
Webster	.0200	0.0571
Wellesley	.0152	0.0314
Weymouth	.0800	0.2286
Woburn	.0229	0.0343

(Report Massachusetts Board of Health, 1900, page 490.)

lacking, the solvent power of the water will be greatly reduced.

EFFECT OF WATER UPON LEAD.—Water containing a fixed amount of oxygen and a varying amount of carbonic

acid acts upon lead with an energy proportional to the amount of carbonic acid present. The action of water upon a bright lead surface is much more energetic than upon a dull lead surface. Thus, city rain water, stored for 3½ months in contact with new and old lead surfaces, was

TABLE XXV. Lead in Samples of Ground Waters

ARRANGED ACCORDING TO AVERAGE AMOUNT OF LEAD FOUND WHEN WATER IS IN ORDINARY USE

(PARTS PER 100,000—.05 PART PER 100,000, DANGEROUS.)

LOCALITY	SAMPLES TAKEN	Lead (Average)	Average Length of Pipe (Feet)	Average Size of Pipe (Ins.)	Free C. O. 2	Hardness
Lowell (cook & hyd. wells)	In ordinary use	.1608	79	¾	3.287	3.5
	After standing in pipe	.2535				
Middleborough	In ordinary use	.1549	123	¾	4.148	2.6
	After standing in pipe	.6171				
Attleborough	In ordinary use	.0697	95	1	3.242	1.7
	After standing in pipe	.0905				
Newton	In ordinary use	.0432	179	¾	1.187	2.2
	After standing in pipe	.0908				
Ayde Park (old) Wells)	In ordinary use	.0400	43	¾	3.243	4.6
	After standing in pipe	.3029				
Lowell (boulevard wells)	In ordinary use	0202	62	¾	1.301	1.5
	After standing in pipe	.0861				
Grafton	In ordinary use	.0187	265	⅞	1.912	3.2
	After standing in pipe	.0329				
Hyde Park (new wells)	In ordinary use	.0172	32	¾	2.733	2.9
	After standing in pipe	.0329				
Wellesley	In ordinary use	.0101	98	¾	1.092	2.3
	After standing in pipe	.0219				
Webster	In ordinary use	.0100	76	¾	1.689	0.8
	After standing in pipe	.0286				
Needham	In ordinary use	.0091	112	¾	2.392	2.1
	After standing in pipe	.0269				
Dedham	In ordinary use	.0082	230	¾	1.611	4.1
	After standing in pipe	.0150				
Brookline	In ordinary use	0074	461	¾	1.149	4.7
	After standing in pipe	.0197				
Bridgewater	In ordinary use	.0057	127	¾	1.084	2.6
	After standing pipe	.0143				
North Attleborough	In ordinary use	.0049	144	¾	1.529	2.9
	After standing in pipe	.0226				
Cohasset	In ordinary use	.0048	39	1	2.411	6.3
	After standing in pipe	.0043				

(Report Massachusetts State Board of Health, 1900, page 491.)

found to contain in suspension and solution the following amount of lead:

*Stored in old lead,	3.65 parts per million
Stored in new lead,	58.10 parts per million

The importance of this will be realized when it is known that 0.5 part of lead per million is considered by most authorities the danger limit.

At Lowell, Mass.†, the water from a well that caused a serious outbreak of lead poisoning was found, upon analysis, to be heavily charged with carbonic acid and to contain 2.30 parts of lead per million.

Hard waters generally protect lead pipe by depositing on the inner surface an insoluble coating. As a rule, the

TABLE XXVI. Lead in Samples of Surface Waters

ARRANGED ACCORDING TO AVERAGE AMOUNT OF LEAD FOUND WHEN WATER IS IN ORDINARY USE

(PARTS PER 100,000—.05 PART PER 100,000, DANGEROUS.)

LOCALITY	SAMPLES TAKEN	Lead (Average)	Average Length of Pipe (Feet)	Average Size of Pipe (Ins.)	Free C. O.2	Hardness
Lawrence........	In ordinary use........	.0543	104	¾	1.100	1.6
	After standing in pipe..	.0704				
Weymouth......	In ordinary use........	.0314	109	¾	0.152	0.3
	After standing in pipe..	.1167				
Metropolitan supply........	In ordinary use........	.0111	85	¾	1.105	1.3
	After standing in pipe..	.0293				
Andover.........	In ordinary use........	.0108	122	¾	0.119	1.0
	After standing in pipe..	.0257				
Beverly..........	In ordinary use........	.0087	84	¾	0.121	2.3
	After standing in pipe..	.0147				
Cambridge.......	In ordinary use........	.0025	58	¾	1.225	2.7
	After standing in pipe..	.0064				

(Report Massachusetts State Board of Health, 1900, page 491.)

harder the water, as compared with the free carbonic acid, the less effect the water has upon the lead. Ground water is generally more energetic than surface water in its action upon lead, although surface water is more liable to become contaminated with sewage, in which case the resultant

*Mason Water Supply, page 398.

†Massachusetts State Board of Health Report, 1900, page 488.

carbonic acid would make it more dangerous than ground water.

An idea of the amount of lead dissolved from lead pipes by different kinds of water can be found in Tables XXIV, XXV, XXVI. In these tables the quantity of lead dissolved is stated in parts per 100,000 in which amounts .05 part of lead is considered the danger limit.

TABLE XXVII. Zinc in Samples of Ground Water

(PARTS PER 100,000.)

LOCALITY	SAMPLES TAKEN	Zinc (Average)	Average Length of Pipe (Feet)	Average Size of Pipe (Inches)
West Berlin	In ordinary use	1.8469	Galv. Iron	
	After standing in pipe	.....	4,000	..
Millbury	In ordinary use	.3084	53	¾
	After standing in pipe	.7931		
Newton	In ordinary use	.1254	74	¾
	After standing in pipe	.5551		
Marblehead	In ordinary use	.0857	65	⅝
	After standing in pipe	.4914		
Grafton	In ordinary use	.0733	117	¾
	After standing in pipe	.3257		
Lowell (cook and hyd. wells)	In ordinary use	.....	Brass	¾
	After standing in pipe	.2867	40	
Wellesley	In ordinary use	.0686	60	¾
	After standing in pipe	.2257		
Fairhaven	In ordinary use	.0527	.....	..
	After standing in pipe	.6686		
Lowell (boulevard wells)	In ordinary use	.0338	90	1⅛
	After standing in pipe	.1522		
Webster	In ordinary use	.0286	Galv. Iron	
	After standing in pipe	.3628	100	½
Reading	In ordinary use	.0000	40	..
	After standing in pipe	.0000		
Warren	In ordinary use	.0000	Galv. Iron	
	After standing in pipe	.0000	Cistern	..

(Report Massachusetts State Board of Health, 1900, page 495.)

These tables all show the increased amount of lead dissolved from pipes by water that was standing for some time, and indicate the additional protection to health that can be obtained by allowing the water in the service pipe to run to waste before drawing any for cooking or drinking purposes.

EFFECT OF GALVANIZED PIPE UPON WATER.—Zinc coatings on the surface of galvanized iron pipe are attacked and dissolved by some waters almost as energetically as is lead

pipe. Zinc is also dissolved to a considerable extent from brass pipes. At Cwmfelin,* galvanized iron pipe that conducts water from a spring to the town, a distance of one-half mile, was found to change the character of the water as shown by the following analysis:

	At Spring	At Delivery
Free ammonia	none	114
Nitrogen as nitrates	.8	none
Total residue	154.3	270
Zinc carbonate	none	91.6

TABLE XXVIII. Zinc in Samples of Surface Water

(PARTS PER 100,000.)

LOCALITY	SAMPLES TAKEN	Zinc (Average)	Average Length of Pipe (Feet)	Average Size of Pipe (Inches)
Sheffield	In ordinary use	.8657	Galv. Iron	
	After standing in pipe	.....	246	¾
Palmer	In ordinary use	.2900	.....	..
	After standing in pipe	.4280		
Beverly	In ordinary use	.2714	1,128	2
	After standing in pipe	.....		
Fall River	In ordinary use	.0070	49	⅝
	After standing in pipe	.0103		
Metropolitan supply	In ordinary use	.0000	Brass	
	After standing in pipe	.0000	92	1

(Report Massachusetts State Board of Health, 1900, page 495.)

The effects on ground and surface waters that are conducted through galvanized iron service pipes can be judged from the results in Tables XXVII and XXVIII.

TABLE XXIX. Copper in Samples of Ground Water

(PARTS PER 100,000.)

LOCALITY	SAMPLES TAKEN	Copper (Average)	Average Length of Brass Pipe (Feet)	Average Size of Pipe (Inches)
Wellesley	In ordinary use	.0257	60	¾
	After standing in pipe	.0286		
Lowell (boulevard wells)	In ordinary use	.0076	90	1⅛
	After standing in pipe	.0233		
Lowell (cook and hyd. wells)	In ordinary use	.....	40	¾
	After standing in pipe	.0060		

*"Chemical News" X—X—'85.

To briefly sum up, it may be stated that it is always better to determine experimentally the action of water upon pipes than to try and predict it from knowledge of the character of the water. It is better still to only use pipes that are not affected to any appreciable extent by the solvent action of any water. If, however, pipes must be used that are so affected, then those should be selected, the dissolved metals of which are the least injurious to the human system.

The necessity of using pipes that are not injurious is manifest, when it is considered that a water which is perfectly wholesome and non-solvent may be changed at any time for a different supply that might energetically attack the pipes, or, the character of the water itself might change sufficiently to dissolve the metal.

Copper is also dissolved from brass pipes, as may be seen from Tables XXIX and XXX of analysis of ground and surface waters drawn from brass service pipes.

TABLE XXX. Copper in Samples of Surface Water

(PARTS PER 100.000.)

LOCALITY	SAMPLES TAKEN	Copper (Average)	Average Length of Brass Pipe (Feet)	Average Size of Pipe (Inches)
Malden	In ordinary use	.0000	20	5/8
	After standing in pipe	.0470		
Metropolitan supply	In ordinary use	.0050	92	1
	After standing in pipe	.0000		
Lawrence	In ordinary use	.0000	10	3/4
	After standing in pipe	.0000		
Wakefield	In ordinary use	.....	6	1/2
	After standing in pipe	.0000		

The effect of some water upon different metals of which water pipes are made or coated, and the resultant effect upon the health of those drinking the waters are shown in Table XXXI.

The action of water upon galvanized iron pipes is almost as energetic as upon lead pipes, and under suitable conditions will dissolve equal amounts of metal from each. However, the effect of the zinc upon the health is not dangerous but only injurious, because zinc is not a cumulative

TABLE XXXI. Effect of Metals on Health

Kind of Pipe	Action of Water	Effect upon People
Lead pipe	Dissolves lead	Dangerous
Tin or tin lined lead	No effect	No effect
Galvanized iron	Dissolves zinc	Injurious
Tin lined iron	No effect	No effect
Brass pipe	Slightly dissolves copper and zinc	Objectionable
*Plain iron	Rusts and dissolves	Objectionable
Aluminum	No effect	No effect
Nickel	No effect	No effect
Benedict Nickel	No effect	No effect
Copper	Dissolves Copper Slightly	No effect

*Dissolved iron or rust in small quantities is not injurious to health, but ¼ grain of iron per gallon of water imparts an objectionable taste to the water besides making it unfit for washing and for most manufacturing purposes.

poison, and so long as the initial dose is not sufficient to cause illness or death, the effect is soon thrown off without apparent injury. Lead, on the contrary, even when taken in small doses, remains in the system until sufficient poison accumulates to cause serious illness or death, or if the initial dose is of sufficient strength the effect may be immediately fatal.

Lead pipes are used for water supply in building. Sheet lead also is used for lining water tanks. Within the past few years, however, a rational decrease in the use of lead supply pipes and lead lined tanks is noticeable. Galvanized iron pipes, which are cheaper and better in every way, are fast supplanting lead pipes, and when perfect security from metal poisoning is desired, Benedict nickel seamless tubing, tin-lined lead or tin-lined iron pipes may be used. From a hygienic standpoint, Benedict nickel and tin-lined pipes are about equal, but when superior finish is desired the Benedict nickel tubing will be found the more satisfactory. In appearance it is equal to nickel-plated brass pipe, and in all other respects superior to it.

ABSORPTION OF GASES BY WATER.—Water has a certain affinity for most gases. This affinity is more pronounced for some gases than for others; for instance, at atmospheric pressure and at ordinary temperatures, pure water will absorb 4 per cent. of its own volume of air, 4 per cent. of its

volume of sulfureted hydrogen, or 100 per cent. of its volume of carbonic acid gas. By increasing the pressure on the water its capacity for absorption is increased in direct proportion. That is, if the pressure be increased to two atmospheres, the temperature remaining unchanged, pure water will absorb 8 per cent. of its own volume of air, 8 per cent. of its volume of sulfureted hydrogen or 200 per cent. of its volume of carbonic acid gas.

Heating water lessens its capacity for absorption in direct proportion to the amount of heat applied. The relative volume of gas absorbed is in all cases directly as the pressure and inversely as the temperature. Thus, if the pressure be increased it will absorb more gas, and if it be heated it will absorb correspondingly less gas. Water is saturated when it has in solution all the gas it can hold. If water is saturated with gas and the pressure is then increased or the temperature lowered, the capacity of the water to hold gas will be increased and it will absorb still more. If water is saturated with gas and the pressure is reduced or its temperature raised, the capacity of the water to hold gas will be reduced and some will be liberated.

It is due to the fact that increasing the pressure of water increases its capacity to absorb gases that necessitates frequent recharging of air chambers in pipe systems. Water usually enters a supply system from a pump or reservoir at atmospheric pressure, saturated with air. As the water becomes compressed, however, its capacity to absorb air is increased, hence, when passing an air chamber the water absorbs air from the chamber, which in turn gradually fills with water.

The fact that decrease of pressure liberates air from saturated waters determines the best place in a system to locate air chambers. When a faucet is opened the pressure of water at that point is considerably reduced; furthermore, in passing through the system of piping within the building the water has become slightly warmed; hence, if an air chamber is located immediately above the faucet, gases liberated from the water will rise into the air chamber and keep it charged.

CHAPTER XIV
HYDRODYNAMICS

HYDROSTATICS

Laws of Hydraulic Pressure

THE HYDRAULIC GRADIENT.—The surface of water at rest is always level. If two or more vessels are connected together near their bottoms and water is poured into one vessel, it will flow through the connecting pipes to the several vessels until the surface of water in all of them is at the same level.

If water in the system of piping, Fig. 62, be at rest, it will stand in all of the branches open to the atmosphere at the top at the same level *d* as the water in the tank. This lined is called the *hydrostatic gradient.* If the cock *b* be now opened the water in the several branches will fall to the dotted line *c* drawn from the surface of the water in the tank to the outlet of the cock. This line is known as the *hydraulic gradient,* and its distance above a pressure main determines the available pressure head at that point, when water is flowing through the pipe. It should be noticed that the *pressure head* differs from the *hydrostatic head;* the latter is equal to the vertical distance from the water pipe to the hydrostatic gradient *d,* while the pressure head is equal to only the vertical distance from the water pipe to the hydraulic gradient *c*. When water from one tank or reservoir discharges into another tank or reservoir at a lower level, the hydrostatic gradient becomes an imaginary line drawn from the surface of water in the upper tank or reservoir to the surface of water in the lower one. An open conduit between two such reservoirs will conduct water from the higher to the lower one without overflowing the conduit, provided the conduit follows the line of the hydraulic gradient and at no point rises above nor dips below it. When running siphon pipes or other closed conduits from a reservoir or other source of water supply to a build-

ing, care should be taken to keep the pipe below the hydraulic gradient. When, however, it is impracticable to do so, a relief valve or open vent should be provided at the highest point of the line where it rises above the hydraulic grade. If means are not provided to permit the escape of air from the pipe, it will accumulate at this point until it fills the bend of the pipe and by forming an air lock might completely stop the flow of water. If the flow of water is not completely stopped, other important changes will result; if a vacuum gauge is attached to the pipe at any point where it rises above the hydraulic gradient it will show a partial vacuum; this vacuum will cause air to collect at the highest point in the pipe and the flow of water will become broken until finally the pipe will be filled only to the point where it rises above the hydraulic gradient and will discharge at this point as though discharging into the air. From the highest point to the outlet, the pipe will be only partly filled and will act as a flume or channel to carry off the water.

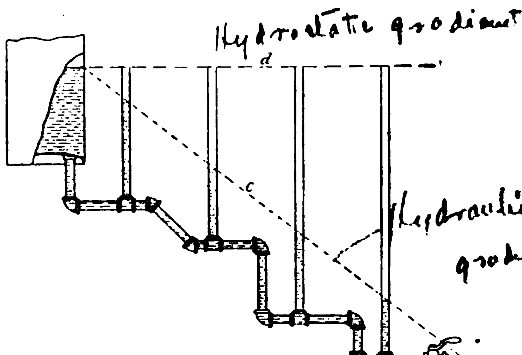


Fig. 62
Hydraulic Gradient

PRESSURE OF WATER.—The unit of water pressure is the pound per square inch. The pressure exerted by water is due to its weight and is determined by the height of the column of water. For instance, if the pressure exerted by a force pump is 50 pounds per square inch it will balance a column of water about 115 feet high. This pressure, therefore, is equivalent to a head of water 115 feet deep. Head of water at a given point is the vertical distance between that point and the level of the surface of the water. In measuring the depth or static head of water, the vertical distance from the hydrostatic gradient to the point of consideration

is always taken regardless of lateral or horizontal distances from the point.

The weight of a column of water one inch square and 12 inches high equals .434 pound. It is just 1/144 the weight of one cubic foot of water which has the same depth of column but 144 times the area. When the height of a column of water is known, its pressure in pounds per square inch can be determined by multiplying the height in feet by .434*, the weight of one foot of water 1 inch square.

EXAMPLE--What is the pressure per square inch at the base of a column of water 200 feet high?

SOLUTION--$200 \times .434 = 86.8$ pounds per square inch.

When the pressure is known the height or head of a column of water can be found by multiplying the pressure in pounds by 2.3, the height of a column of water weighing one pound.

EXAMPLE--What must be the height of a column of water to exert a pressure of 86.8 pounds per square inch?

SOLUTION--$86.8 \times 2.3 = 199.64$ feet head.

The constants .434 and 2.3 although used in practice are not exactly correct, as can be seen by comparing the two foregoing examples.

Heads and corresponding pressures of water in pounds per square inch for every foot in height to 240 feet can be found in Table XXXII.

PASCAL'S LAW OF PRESSURE.—Water confined in a vessel and subjected to a pressure, transmits the pressure with the same intensity in all directions. This law was first discovered by Pascal, and is expressed as follows: "The pressure per unit of area exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force upon all surfaces, in a direction at right angles to the surfaces."

MEASURING PRESSURE.—The pressure of water in closed systems is indicated by a pressure gauge. The construction

*The constant .434 will be found sufficiently accurate for most calculations, and when an approximation only is required the constant .4 will suffice.

TABLE XXXII. Heads and Pressures of Water

Feet Head	Pressure per Sq. Inch	Feet Head	Pressure per Sq. Inch	Feet Head	Pressure per Sq. Inch	Feet Head	Pressure per Sq. Inch	Feet Head	Pressure per Sq. Inch
1	0.43	49	21.22	97	42.01	145	62.81	193	83.60
2	0.86	50	21.65	98	42.45	146	63.24	194	84.03
3	1.30	51	22.09	99	42.88	147	63.67	195	84.47
4	1.73	52	22.52	100	43.31	148	64.10	196	84.90
5	2.16	53	22.95	101	43.75	149	64.54	197	85.33
6	2.59	54	23.39	102	44.18	150	64.97	198	85.76
7	3.03	55	23.82	103	44.61	151	65.40	199	86.20
8	3.46	56	24.26	104	45.05	152	65.84	200	86.63
9	3.89	57	24.69	105	45.48	153	66.27	201	87.07
10	4.33	58	25.12	106	45.91	154	66.70	202	87.50
11	4.76	59	25.55	107	46.34	155	67.14	203	87.93
12	5.20	60	25.99	108	46.78	156	67.57	204	88.36
13	5.63	61	26.42	109	47.21	157	68.00	205	88.80
14	6.06	62	26.89	110	47.64	158	68.43	206	89.23
15	6.49	63	27.29	111	48.08	159	68.87	207	89.66
16	6.93	64	27.72	112	48.51	160	69.31	208	90.10
17	7.36	65	28.15	113	48.94	161	69.74	209	90.53
18	7.79	66	28.58	114	49.38	162	70.17	210	90.96
19	8.22	67	29.02	115	49.81	163	70.61	211	91.39
20	8.66	68	29.45	116	50.24	164	71.04	212	91.83
21	9.09	69	29.88	117	50.68	165	71.47	213	92.26
22	9.53	70	30.32	118	51.11	166	71.91	214	92.69
23	9.96	71	30.75	119	51.54	167	72.34	215	93.13
24	10.39	72	31.18	120	51.98	168	72.77	216	93.56
25	10.82	73	31.62	121	52.41	169	73.20	217	93.99
26	11.26	74	32.05	122	52.84	170	73.64	218	94.43
27	11.69	75	32.48	123	53.28	171	74.07	219	94.86
28	12.12	76	32.92	124	53.71	172	74.50	220	95.30
29	12.55	77	33.35	125	54.15	173	74.94	221	95.73
30	12.99	78	33.78	126	54.58	174	75.37	222	96.16
31	13.42	79	34.21	127	55.01	175	75.80	223	96.60
32	13.86	80	34.65	128	55.44	176	76.23	224	97.03
33	14.29	81	35.08	129	55.88	177	76.67	225	97.46
34	14.72	82	35.52	130	56.31	178	77.10	226	97.90
35	15.16	83	35.95	131	56.74	179	77.53	227	98.33
36	15.59	84	36.39	132	57.18	180	77.97	228	98.76
37	16.02	85	36.82	133	57.61	181	78.40	229	99.20
38	16.45	86	37.25	134	58.04	182	78.84	230	99.63
39	16.89	87	37.68	135	58.48	183	79.27	231	100.06
40	17.32	88	38.12	136	58.91	184	79.70	232	100.49
41	17.75	89	38.55	137	59.34	185	80.14	233	100.93
42	18.19	90	38.98	138	59.77	186	80.57	234	101.36
43	18.62	91	39.42	139	60.21	187	81.00	235	101.79
44	19.05	92	39.85	140	60.64	188	81.43	236	102.23
45	19.49	93	40.28	141	61.07	189	81.87	237	102.66
46	19.92	94	40.72	142	61.51	190	82.30	238	103.09
47	20.35	95	41.15	143	61.94	191	82.73	239	103.53
48	20.79	96	41.58	144	62.37	192	83.17	240	103.96

of a pressure gauge is shown in Fig. 63. In this illustration the dial face is removed to show the interior construction. A bent tube *a*, of elliptical cross-section, made of metal of the required elasticity, has its bottom end firmly attached to the gauge case, and its upper end left free to move. To the upper end is attached a lever *b*, which is so connected to a pointer in front of a graduated index dial that any movement of the tube will be indicated by the pointer.

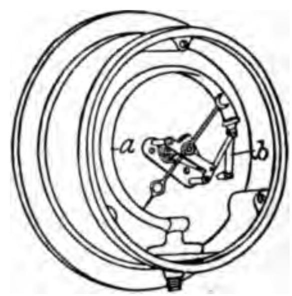


Fig. 63
Pressure Gauge

The principle of its operation is as follows: If a bent tube of elliptical cross section be subjected to an internal pressure, the force exerted will tend to straighten the tube. This is due to the fact that a force exerted within a tube of elliptical cross section tends to make it take a circular form; to do so, the inner arc of the bent tube must lengthen and the outer arc shorten and the combined effort will straighten the tube in direct proportion to the pressure exerted. The straightening of the tube imparts a movement to the register hand which indicates on the face of the gauge the intensity of the pressure.

CHAPTER XV
FLOW OF WATER THROUGH PIPES

FRICTION IN PIPES.—The flow of water through pipes is accelerated by gravity and retarded by friction. If it were not for the frictional resistance in pipes, water would flow through them with a velocity equal to eight times the square root of the head. As it is, the roughness of the interior walls, the bends and branch fittings in a system of piping offer so much frictional resistance that the actual mean velocity is but a fraction of the theoretical velocity.

The pressure head at any point is less than that due to the hydrostatic head. This difference between the hydrostatic head and the pressure head is known as *loss of head,* and is greater the smaller the pipe or the greater the velocity of flow. The loss of head is due to three causes—loss of head due to entry, loss of head due to bends, and loss of head due to the length and area of the pipe.

THE CONTRACTED VEIN.—The flow of water through a circular aperture in a thin plate, Fig. 64, is contracted in size a short distance outside of the plate to .615 the area of the aperture, but expands again to the full size of the opening. The point of greatest contraction is at a distance from the plate equal to about one-half the diameter of the aperture.

In consequence of this contraction, the velocity of flow is slightly reduced from the theoretical velocity and the quantity discharged is greatly reduced. This contraction is known as the *contracted vein.*

When the aperture is through a plate of considerable thickness or through a tube the length of which is not less than twice the diameter of the pipe, the contraction is still found to occur, but to a less extent than in the former case; the vein being contracted, as shown in Fig. 65, to only .8 of the theoretical area due to head and aperture.

Loss due to the contracted entrance of water from a tank or cylinder into the end of a pipe, as commonly found in practice, must be taken then as .2 the quantity that

should pass. This loss is known as loss of head due to entry and is considered separate from the loss due to friction in long pipes, loss for bends, branches, etc., and should be added thereto.

The actual loss of head due to entry can be reduced to a quantity too small to be considered by enlarging the entrance to the pipe and making it cone shaped, as in Fig. 66. The cone should have a length *a*, equal to one-half the diameter of the pipe, and a radius *b*, equal to 1.22 diameters of the pipe. Any greater enlargement of the opening will deduct but little from the loss of head. If the ends of thick pipes or pipes of small diameter which are relatively thick are reamed with a reamer, the length of which is just twice the base, enough metal will be removed to give almost the best form of contracted vein.

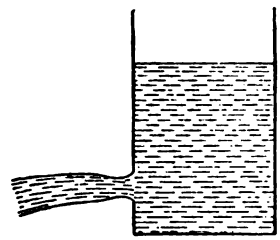


Fig. 64
Contracted Vein

When an unreamed pipe projects a short distance inside of a tank the loss of head due to entry is greater than when the pipe finishes flush with the inside of the tank. This loss of head has been found by experiment to be over .3 of the whole flow, thus decreasing it one-tenth more than a pipe that finishes flush with the inside of a tank.

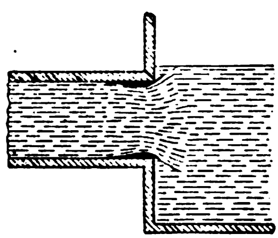


Fig. 65
Water Flowing Through Short Tube

Loss of head due to entry can be determined by the formula:

$l = c\frac{v^2}{2g}$ When l = loss of head in feet, v = velocity of flow in feet per second, g = 32.16, acceleration due to gravity, c = coefficient depending on shape of the pipe inlet.

For ordinary calculations the value of *c* may be taken as .5.

EXAMPLE—What is the loss of head due to entry in a pipe when the velocity of flow is 8 feet per second?

SOLUTION—$l = .5\frac{64}{64.32} = .497$ feet. Answer.

LOSS OF HEAD IN BENDS.—The loss of head, due to bends in a pipe, depends upon three factors. First, loss due to change of direction of the water in the pipe; second, loss from friction as in an ordinary straight length of pipe; third, loss due to enlargements or contractions in the bend, such as are formed when the unreamed ends of pipe are screwed into ordinary elbows.

The second and third losses also apply to couplings and tees, but the loss is not the same as for bends of equal diameters. The loss of head for change of direction differs with the angle and with the radius of the bend. That is, there is less loss for change of direction in a forty-five degree bend than in a ninety-degree bend, and the loss is greater in a bend of one diameter radius than in one with a radius of two diameters. The loss in a ninety degree bend with a radius of five or more diameters and uniform smooth interior bore is no greater than in an equal length of straight pipe. In other words, there is practically no loss for change of direction in a bend of greater radius than 5 diameters.

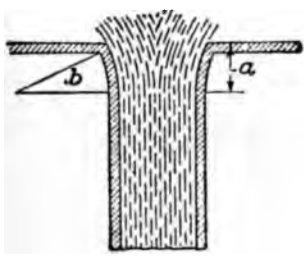


Fig. 66
Cone Shaped Entry to Pipe

The head lost in a ninety degree bend of less than 5 inch diameter and of the radius commonly found in practice, radius=diameter, with square unreamed ends of pipe screwed into the fitting, as shown in Fig. 67, is found by experiment to be five times as great as in bends, which the pipes have reamed ends.

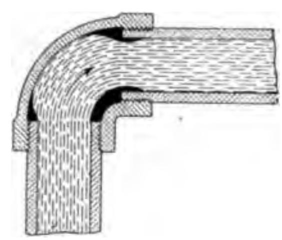


Fig. 67
Friction in Bends

The friction loss in bends having reamed pipes screwed therein, is given in Table XXXIII for various sizes of pipe. It will be observed that the larger the size of the pipe, the greater the equivalent length of pipe the friction in the bend equals. In the experiments from which these tables were derived, the ends of the pipes were reamed and filed

out to such an extent that there was practically no decrease of diameter at these points.

TABLE XXXIII. Friction in Pipe Bends

Diameter of Bend in Inches	Friction in the bend is equal to the friction in number of feet of straight pipe listed	Friction in the bend equals the friction in corresponding sizes of straight pipe of the following lengths
5	20 feet of straight pipe	48* diameters of fitting
4	15 feet of straight pipe	45 diameters of fitting
3	9 feet of straight pipe	36 diameters of fitting
2	5 feet of straight pipe	30 diameters of fitting
1½	3 ft. 3 in. of straight pipe	26 diameters of fitting
1¼	2 ft. 6 in. of straight pipe	24 diameters of fitting
1	1 ft. 6 in. of straight pipe	18 diameters of fitting

*Thus, 18 diameters of 1 inch pipe equals 18 inches of straight pipe.

For use in practice the value given in Table XXXIV may be taken as the approximate ratios between the friction of ninety degree bends and other fittings of the same size.

TABLE XXXIV. Friction of Fittings

Kind of Fitting	Number of 90° bends it is equal to in frictional resistance
Coupling	One-tenth of 90° bend. About twice the friction of corresponding length of straight pipe.
45° elbow	One-half the friction of a 90° bend.
Open return bend (open pattern)	Same as 90° bend.
Tee fitting	Equals friction in two 90° bends.
Gate valve	One-half the friction of a 90° bend.
Globe valve	Equals friction in twelve 90° bends.

In pipes of larger diameter than 5 inches, these ratios would hold true, but the number of diameters of straight pipe a fitting would equal in frictional resistance would increase in proportion and can be found by interpolation.

The loss of head in small fittings when the ends of the pipe screwed into the fitting are reamed, as shown in Fig. 68, is found by experiment to be less by about five times as when the pipe ends are not reamed. For instance, in a 1 inch ninety degree bend, with reamed pipe ends, in which

Note: Tables XXXIII and XXXIV based on experiments made by Professor F. E. Geisule, School of Architecture, Austin, Texas.

the friction is equal to friction in a pipe of a length of 18 diameters, this loss of head would be divided into:

Loss of head due to change in direction	12 diameters
Loss of head due to enlargement of the bend	4 diameters
Loss of head from friction due to length of fitting	2 diameters
Total	18 diameters

In a bend having unreamed pipe ends, the friction would be about 5 times as great, or equal to $5 \times 18 = 90$ diameters of the pipe.

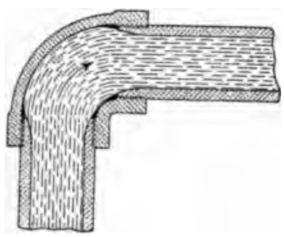


Fig. 68
Elbow With Reamed Pipes

The loss of head in a bend of five or more diameter radius, with flush interior joints, Fig. 69, is equal to the loss of head in a length of pipe four diameters of the fitting. This is comparatively shown as follows:

Loss of head due to change of direction	0 diameters
Loss of head due to enlargement of the bend	0 diameters
Loss of head from friction due to length of pipe	4 diameters
Total	4

From the foregoing it will be seen that the least possible head is consumed by using fittings of large radius with flush joints. That when common fittings are used the loss can be reduced to one-fifth by reaming the ends of the pipe with a triangular-shaped reamer, the length of which is just double the base.

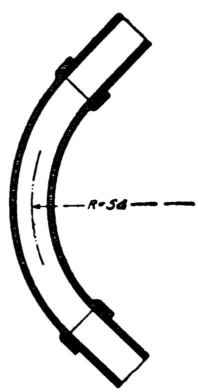


Fig. 69
Friction in Flush Fitting

The values for friction loss in fittings given in the preceding tables are relative and for low velocities, not over 1 foot per second. With an increase in velocity, however, there is an increase in frictional resistance, so for greater velocities the friction will have to be approximated by calculation.

The loss of head in feet due to bends can be calculated by the formula:

$h = n\frac{v^2}{2g}$ in which h = head lost in feet, v = velocity in feet per second, g = 32.16 acceleration due to gravity, n = a coefficient for the bend.

The value of coefficient *n* depends upon the ratio between the radius *r* of the pipe and the radius R of the bend. Table XXXV gives values of *n* corresponding to various values of the ratio $\frac{r}{R}$.

EXAMPLE—What will be the loss of head in a column of water flowing with a velocity of 8 feet per second through a 4-inch bend that has a radius R of 4 inches?

SOLUTION—The radius r of a 4-inch bend = 2 inches, therefore, R which is 4 inches will = 2r, which gives for *n* the value .29. Substituting values in the formula then gives, $h = .29 \times \frac{64}{64.32} = .287$ foot. Answer.

TABLE XXXV. Values of Coefficient *N*

$\frac{r}{R}$ =	R = r	R = 1.12r	R = 1.25r	R = 1.4r	R = 1.6r	R = 2r	R = 2.5r	R = 3.3r	R = 5r
n	1.98	1.41	.98	.66	.44	.29	.21	.16	.14

LOSS OF HEAD IN STRAIGHT PIPES.—Loss of head in straight pipes is caused entirely by the frictional resistance of the walls of the pipes; the rougher the walls, the greater the amount of frictional resistance offered to the flow. Frictional resistance in pipes may be summed up in three general laws, viz.:

1. Frictional resistance in a pipe varies directly as the length of the pipe. That is, the total amount of friction offered in a pipe 100 feet long is twice as much as in a pipe 50 feet long, of equal diameter and smoothness, and one-half as much as in a pipe 200 feet long.

2. Friction varies inversely as the diameter of the pipes. That is, in a pipe 2 inches in diameter the frictional resistance is proportionately less by one-half than in a pipe 1 inch in diameter. The reason is that frictional resistance is in direct proportion to the area of the surface of water and walls of pipe in contact. This surface is known as the wetted perimeter, and in a pipe 2 inches in diameter is but twice as great as the surface in a 1 inch pipe, while

the cross sectional area of the 2 inch pipe, it will be remembered, is 4 times as great as that of a 1 inch pipe.

This is well illustrated in Fig. 70. In the four 1 inch pipes, *a*, *b*, *c*, *d*, the length of the wetted perimeter is just 13.16 inches. If the four 1-inch pipes be now converted into one 2-inch pipe by removing the sections marked with dotted lines and rolling the heavy lined sections back to *e*, the wetted perimeter will be reduced to 6.49 inches, or about one-half the length of the combined perimeters of the four 1-inch pipes, while the sectional area remains unchanged.

3. Friction varies almost as the square of the velocity and is entirely independent of pressure. That is, if the velocity of flow of water in a pipe is doubled, the frictional resistance will be quadrupled, while if the initial velocity is reduced to one-half, the frictional resistance will be decreased to one-quarter, regardless of the intensity of pressure in the pipe.

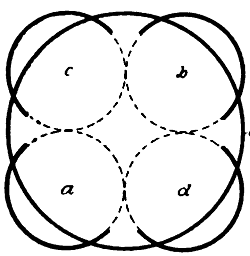


Fig. 70
Wetted Perimeter of Pipes

Loss of head due to friction in pipes can be determined by the formula:

$h = f\dfrac{lv}{d\,2g}$, in which h = loss of head in feet, f = coefficient for size and roughness of pipe, l = length of pipe in feet, v = velocity in feet per second, d = diameter of pipe in feet, g = 32.16 acceleration due to gravity.

The value of coefficient *f* for different sizes of pipes

TABLE XXXVI. Values of Coefficient *F*

(MERRIMAN)

Diameter of Pipe in		Velocity of Feet per Second						
Ft.	In.	1	2	3	4	6	10	15
.05	⅝	.047	.041	.037	.034	.031	.029	.028
.1	1¼	.038	.032	.030	.028	.026	.024	.023
.25	3	.032	.028	.026	.025	.024	.022	.021
.5	6	.028	.026	.025	.023	.022	.021	.019
.75	9	.026	.025	.024	.022	.021	.019	.018
1.	12	.025	.024	.023	.022	.020	.018	.017

and with different velocities of flow can be found in Table XXXVI.

EXAMPLE—What is the loss of head due to friction in a 3-inch pipe 600 feet long, if the mean velocity of flow is 4 feet per second?

SOLUTION—From the table it is found that the value of f for a 3-inch pipe with a velocity of 4 feet per second is .025; then, substituting given values in the formula:

$$h = .025 \times \frac{600 \times 16}{.25 \times 64.32} = 15 \text{ feet.—Answer.}$$

Table XXXVII gives the loss of head in pounds per square inch for each 100 feet of length in different sizes of clean pipes discharging given quantities of water per minute.

If the loss of head is desired for the same diameters of pipe but for different lengths than those given in the table, when discharging the given quantities of water, it can be found by multiplying the loss of head by the ratio of the length of pipe. For instance, according to the table there is a loss of head of 13 pounds in a $\frac{3}{4}$-inch pipe when discharging 10 gallons of water per minute, and, as friction, hence loss of head, is in direct proportion to the length of a pipe, velocity and diameter remaining the same, it follows that in a $\frac{3}{4}$-inch pipe 200 feet long, discharging 10 gallons of water per minute, the loss of head would be 26 pounds, or double that in 100 feet of pipe. Likewise, in a pipe of equal diameter but only 50 feet long, discharging 10 gallons of water per minute, the loss of head would be 6.5 pounds, or one-half that of 100 feet of pipe.

If the loss of head expressed in pounds is desired in feet, it can be found by multiplying the loss of head in pounds by 2.3. The size of pipes and quantity of discharge being given in this table, the velocity of flow can be found by dividing the quantity by the area of the pipe.

VELOCITY OF FLOW.—When water flows through a pipe of uniform cross section, the quantity of water passing any point in a given interval of time depends upon the velocity with which the water flows and the area of cross section of the pipe. It is evident that the quantity of water will equal a column whose cross section is the area of the pipe and whose length is equal to the velocity.

TABLE XXXVII. Loss of Head in Pounds, in 100 Feet of Straight Pipe

(G. A. ELLIS, C. E.)

Gallons Discharged per Minute	½-inch Velocity in Feet per Second	½-inch Friction Loss in Pounds	¾-inch Velocity in Feet per Second	¾-inch Friction Loss in Pounds	1-inch Velocity in Feet per Second	1-inch Friction Loss in Pounds	1¼-inch Velocity in Feet per Second	1¼-inch Friction Loss in Pounds	1½-inch Velocity in Feet per Second	1½-inch Friction Loss in Pounds	2-inch Velocity in Feet per Second	2-inch Friction Loss in Pounds	2½-inch Velocity in Feet per Second	2½-inch Friction Loss in Pounds	3-inch Velocity in Feet per Second	3-inch Friction Loss in Pounds	4-inch Velocity in Feet per Second	4-inch Friction Loss in Pounds	6-inch Velocity in Feet per Second	6-inch Friction Loss in Pounds	Gallons Discharged per Minute
5	8.17	24.6	3.63	3.3	2.04	0.84	1.31	0.31	0.91	0.12											5
10	16.3	96.0	7.25	13.0	4.08	3.16	2.61	1.05	1.82	0.47	1.02	0.12									10
15			10.9	28.7	6.13	6.98	3.92	2.38	2.73	0.97											15
20			14.5	50.4	8.17	12.3	5.22	4.07	3.63	1.66	2.04	0.42									20
25			18.1	78.0	10.2	19.0	6.53	6.40	4.54	2.62			1.63	0.21	1.13	0.10					25
30					12.3	27.5	7.84	9.15	5.45	3.75	3.06	0.91									30
35					14.3	37.0	9.14	12.4	6.36	5.05											35
40					16.3	48.0	10.4	16.1	7.26	6.52	4.09	1.60									40
45							11.7	20.2	8.17	8.15											45
50							13.1	24.9	9.08	10.0	5.11	2.44	3.26	0.81	2.27	0.35	1.28	0.09			50
75							19.6	56.1	13.6	22.4	7.66	5.32	4.90	1.80	3.40	0.74					75
100									18.2	39.0	10.2	9.46	6.53	3.20	4.54	1.31	2.55	0.33	1.13	0.05	100
125											12.8	14.9	8.16	4.89	5.67	1.99					125
150											15.3	21.2	9.80	7.00	6.81	2.85	3.83	0.69	1.70	0.10	150
175											17.1	28.1	11.4	9.46	7.94	3.85					175
200											20.4	37.5	13.1	12.48	9.08	5.02	5.1	1.22	2.27	0.17	200
250													16.3	19.66	11.3	7.76	6.39	1.89	2.84	0.26	250
300													19.6	28.06	13.6	11.2	7.66	2.66	3.40	0.37	300
350															15.9	15.2	8.94	3.65	3.97	0.50	350
400															18.2	19.5	10.2	4.73	4.54	0.65	400
450															20.4	25.0	11.5	6.01	5.11	0.81	450
500															22.7	30.8	12.8	7.43	5.67	0.96	500

The velocity with which water moves through a pipe is not uniform throughout its cross section. It is least near the wetted perimeter of the pipe where the friction of the pipe retards the flow, and is greatest at the center of the cross section where having to overcome only the friction of its own flowing layers, it attains the maximum velocity. It is assumed in practice, however, that all particles of the water have the same velocity, and the mean of all the velocities in the cross section is taken as the velocity of flow.

FORMULAS FOR VELOCITY.—When the size of a pipe and the quantity of water it will discharge in a given time are known, the mean velocity of efflux can be found by the formula:

$V = \frac{q}{a}$ in which V = velocity of flow in feet per minute, q = quantity of water in cubic feet per minute, a = area of cross section of pipe in square feet.*

EXAMPLE—What must be the velocity of flow in a 2-inch pipe to discharge 6.3 cubic feet of water per minute?

SOLUTION—Area of pipe = .021 square feet. Then 6.3 ÷ .021 = 300 feet per minute.—Answer.

When the hydrostatic head, length and diameter of a pipe are known, the mean velocity of discharge can be found by the formula:

$V = m\sqrt{\frac{hd}{l + 54d}}$, in which V = mean velocity in feet per second, m = coefficient from Table XXXVIII, d = diameter of pipe in feet, h = hydrostatic head in feet, l = total length of pipe in feet.

EXAMPLE—What will be the velocity of discharge from a 6-inch pipe 500 feet long under a head of 60 feet?

SOLUTION—$v = 55\sqrt{\frac{60 \times .5}{500 + (54 \times .5)}} = 55\sqrt{\frac{30}{527}} = 55\sqrt{.0567} = 55 \times .238$ = 13.09 feet per second.—Answer.

In column 1 of Table XXXVIII will be found that the nearest value corresponding to .238 is .20, and following that line to where it intersects the column headed 6 inches, the value of coefficient *m* will be found to be 55, which multiplied by the square root .238 gives the velocity sought for. Where great accuracy of calculation is not required,

*Table of square inches in decimals of a square foot in appendix.

the constant 48, which is an average value of coefficients for small sizes of pipes, can be used, and will give results sufficiently accurate for most practical purposes.

TABLE XXXVIII. Values of Coefficient *M*

$\sqrt{\frac{hd}{1+54d}}$	Diameter of Pipe in							
	Feet .05	Feet .10	Feet .50	Feet 1	Feet 1.5	Feet 2	Feet 3	Feet 4
	Ins. ⅝	Ins. 1¼	Ins. 6	Ins. 12	Ins. 18	Ins. 24	Ins. 36	Ins. 48
	m	m	m	m	m	m	m	m
.005	29	31	33	35	37	40	44	47
.01	34	35	37	39	42	45	49	53
.02	39	40	42	45	49	52	56	59
.03	41	43	47	50	54	57	60	63
.05	44	47	52	54	56	60	64	67
.10	47	50	54	56	58	62	66	70
.20	48	51	55	58	60	64	67	70

FORMULA FOR HEAD.—When the length and diameter of a pipe are known, the head required to discharge a certain quantity of water per second can be found by the formula:

$h = \frac{.000704\, q^2\, l}{d^5}$, in which h = head in feet, l = length of pipe in feet, d = diameter of pipe in feet, q = quantity of water in cubic feet per second.

EXAMPLE—What head will be required to discharge from a 4-inch pipe 500 feet long 2 cubic feet of water per second?

SOLUTION—Substituting values in the formula

$$h = \frac{0.000704 \times 4 \times 500}{0.00422} = 333 \text{ feet head.—Answer.}$$

FORMULA FOR DIAMETER.—When the length of a pipe, the hydrostatic head, and the quantity of water required to be delivered per second are known, the diameter of pipe that will safely take care of that quantity can be found by the formula:

$d = .234\sqrt[5]{\frac{q^2\, l}{h}}$, in which d = diameter of pipe in feet, q = cubic feet per second to be delivered, l = length of pipe in feet, h = head in feet.

EXAMPLE—What diameter of pipe will be required to deliver .5 cubic foot of water per second through a pipe 2,000 feet long with a head of 400 feet?

SOLUTION—$d = .234 \sqrt[5]{\frac{.25 \times 2{,}000}{400}} = .245$ feet = 3-inch pipe.—Answer.

FORMULAS FOR QUANTITY.—When the mean velocity and the area of a pipe are known, the quantity of water discharged in a given interval of time can be determined by the formula:

$q = va$, in which q = quantity of water in cubic feet per minute, v = velocity of flow in feet per minute, a = area of cross section of pipe in square feet.

EXAMPLE—How many cubic feet of water will be discharged per minute by a 2-inch pipe when the velocity of efflux is 300 feet per minute?

SOLUTION—Area of 2-inch pipe = .021 square feet. Then $.021 \times 300 = 6.3$ cubic feet.—Answer.

When the diameter, head and length of a pipe are known, the quantity of water it will deliver in a given time can be found by the formula:

$q = \sqrt{\frac{d^5 h}{l}} \times 4.71$, in which q = quantity in cubic feet per minute, d = diameter of pipe in inches, h = head in feet, l = length of pipe in feet.

EXAMPLE—What quantity of water can be delivered per minute through a 3-inch pipe, 2,000 feet long with a head of 400 feet?

SOLUTION—$q = \sqrt{\frac{243 \times 400}{2{,}000}} \times 4.71 = 32.97$ cubic feet per minute.—Answer.

DISCHARGING CAPACITY OF SMALL PIPES.—It is often convenient to know approximately the number of gallons of water delivered per minute, through pipe of various small sizes. This information will be found in Table XXXIX, where the discharge is given under stated heads in feet for various lengths, and will be useful in laying out service pipes.

EXAMPLE—Given a 2-inch pipe 133 feet long, how much water will it deliver per minute under a head of 100 feet?

SOLUTION—The head equals three-quarters of the length. Under the column $H = ¾L$ and opposite to 2 inch diameter, we find the answer 173.1 gallons. In the same way we will find that a ⅝-inch pipe 75 feet long, under a head of 150 feet ($H = 2L$) will discharge approximately 15.4 gallons per minute.

TABLE XXXIX. Discharging Capacity of Pipes

Diam of Pipe Ins.	H = 10L	H = 9L	H = 8L	H = 7L	H = 6L	H = 5L	H = 4L	H = 3L	H = 2L	H = 1¾L	H = 1½L	H = 1¼L
½	19.8	18.7	17.7	16.5	15.3	14.0	12.5	10.8	8.8	8.3	7.7	7.0
⅝	34.5	32.7	30.1	28.9	26.5	24.4	21.8	18.9	15.4	14.4	13.4	12.2
¾	54.4	51.7	48:7	45.6	42.2	38.5	34.4	29.8	24.3	22.8	21.1	19.3
1	111.8	106.0	100.0	93.5	86.6	79.0	70.7	61.2	50.0	46.8	43.2	39.5
1¼	195.2	185.2	174.6	163.3	151.2	138.0	123.4	106.9	87.3	81.6	75.6	69.0
1½	308.0	292.1	275.4	257.6	238.5	217.7	194.8	168.7	137.7	128.8	119.3	108.9
2	632.2	599.7	566.4	528.9	488.1	447.0	399.8	346.3	282.7	264.4	248.8	223.5
2½	1104.	1048.	987.8	924.0	855.4	780.9	698.5	604.9	493.0	462.0	427.7	390.4
3	1745.	1651.	1560.	1460.	1351.	1234.	1103.	955.5	780.2	728.8	674.8	615.9
4	3581.	3397.	3203.	2996.	2774.	2532.	2265.	1062.	1602.	1496.	1385.	1264.
5	6247.	5928.	5588.	5227.	4839.	4417.	3951.	3406.	2791.	2613.	2420.	2209.
6	9855.	9349.	8814.	8245.	7633.	6968.	6233.	5391.	4407.	4122.	3817.	3484.

Diam. of Pipe Ins.	H = L	H = ¾L	H = ½L	H = 1/3L	H = ¼L	H = 1/5L	H = 1/6L	H = 1/7L	H = 1/8L	H = 1/9L	H = 1/10L	
½	6.3	5.4	4.4	3.6	3.1	2.8	2.6	2.4	2.2	2.1	2.0	......
⅝	10.9	9.5	7.7	6.3	5.5	4.8	4.4	4.1	3.9	3.6	3.5	......
¾	17.2	14.9	12.2	9.9	8.6	7.7	7.0	6.5	6.1	5.7	5.4	......
1	35.3	30.6	25.0	20.4	17.7	15.8	14.4	13.4	12.5	11.8	11.2	......
1¼	61.7	53.5	43.7	35.6	30.9	27.6	25.2	23.3	21.8	20.6	19.5	......
1½	97.4	84.3	68.7	56.2	48.7	43.9	39.8	36.8	34.4	32.5	30.8	......
2	199.9	173.1	141.4	115.4	100.	89.4	81.6	75.6	70.7	66.6	63.2	......
2½	349.2	302.4	246.9	201.6	174.6	156.2	142.6	132.0	123.5	116.4	110.4	......
3	555.5	477.1	390.1	317.8	275.8	246.7	225.2	208.5	195.1	183.9	174.5	......
4	1133.	979.3	800.8	653.8	566.2	506.5	463.2	428.0	399.0	377.5	358.1	......
5	1976.	1711.	1394.	1141.	987.7	883.5	806.5	746.7	698.5	658.5	624.7	......
6	3116.	2693.	2204.	1799.	1558.	1384.	1272.	1178.	1102.	1039.	985.5	......

From this table the discharge of any length of pipe under any head used in practice can readily be determined. The abbreviation H stands for head, and L for length.

Checking up the table with the formula for quantity and the example worked, it will be found that they agree almost exactly. The problem is to find the quantity of water that can be delivered per minute through a 3-inch pipe 2,000 feet long, under a head of 400 feet. According to the example worked out, the pipe has a capacity of 32.97 cubic feet per minute. As there are 7.47 gallons in a cubic foot, the capacity of this 3-inch pipe in gallons is 246.28 per minute.

Now, a pipe 2,000 feet long with a head of 400 feet has a ratio of Head equal to 1/5 its length; and looking on the table it will be found that a 3-inch pipe having a head of 1/5 length, has a capacity of 246.7 gallons per minute, thereby varying from the answer to the example less than one-half gallon per minute.

CHAPTER XVI
MEASUREMENT OF WATER

TYPES OF WATER METERS

Velocity Meters

CLASSIFICATION OF METERS.—The quantity of water flowing uninterruptedly through a pipe may be approximately determined either by calculation or by measurement. When the flow of water is intermittent, however, the quantity can be determined only by measurement. The manner of determining the flow of water by calculation has already been explained. It is measured by means of an apparatus called a water meter.

Water meters may be divided into two general classes: Velocity or inferential meters, and volume or positive meters. Velocity meters measure the velocity of water passing through them, and, the size of the discharge orifice remaining constant, the velocity per foot equals a certain quantity which is automatically computed and indicated on an index dial. Volume meters measure the volume of water passing through them and automatically register the quantity on an index dial; they operate by alternately filling and discharging a chamber of known capacity.

VENTURI METER.—The simplest form of velocity meter is the Venturi meter, Fig. 71. This meter may be had in sizes ranging from 2 inches to 60 inches in diameter, and fitted with an index dial, a recording register, or with a manometer gauge, *a*, which simply indicates the rate of flow. The meter operates on the principle that when water flows through a contraction in a tube of the shape and relative cross sections of a Venturi meter tube, there is a temporary reduction of pressure at the throat *b*, which is approximately proportional to the square of the velocity. This reduction of pressure at the throat causes an unequal pressure in the pressure pipes *c* and *d*, which are connected respectively to the pressure chamber *e* on the inlet end of

the tube and the pressure chamber *f* at the throat of the tube. This unequal pressure depresses the mercury in the leg *g* of the manometer and causes it to rise correspondingly in the other leg; a properly graduated scale showing the difference between these two mercury levels, indicates the velocity of flow through the meter. Having the velocity of flow and knowing the area of cross section of the meter, the quantity of water passing through in a given time can be calculated by multiplying the velocity for that period of time by the cross sectional area of the meter tube.

THE GEM METER.—Fig. 72 clearly illustrates the construction and principle of operation of a mechanical type of velocity meter. Water enters the cylinder from below and in rising presses against the propeller blades *a*, causing them to revolve in direct proportion to the velocity of the water flowing through the meter. The speed of the propeller is so adjusted that a certain number of revolutions equals a certain number of gallons or cubic feet which are automatically indicated on an index dial.

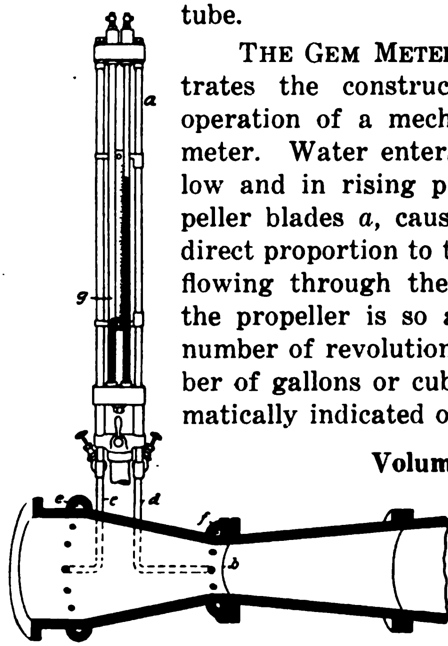


Fig. 71
Venturi Meter

Volume Meters

THE HERSEY DISK METER.—Fig. 73 discharges a known quantity of water at each gyration of the disk *a*, and is therefore a positive or volume meter. The principle of its operation is as follows: Water entering the meter passes through a perforated metal screen *b* to remove all coarse particles of matter that might interfere with the operation of the meter. The water enters the disk chamber on top of the disk *a*, and exerts a pressure there at the same time that the pressure is released in the discharge chamber. This uneven pressure

causes the disk to gyrate, rising on the inlet side and lowering on the discharge side, so that water now enters and presses on the under side of the disk which again gyrates and brings the pressure to the upper side of the disk. The disk is thus alternately raised and lowered at the inlet and outlet ports at each gyration of the disk as long as water is flowing through the pipe.

At each gyration of the disk an amount of water equal to the entire contents of the disk cylinder is discharged and each gyration indicates on the index dial the amount of water that passes through the meter.

Meter Accessories

FISH TRAPS.—In localities where the water supply is obtained from rivers, lakes, reservoirs or other surface sources, fish traps should be used to prevent the introduction of fish, algæ, weeds or objects that might interfere with the operation of the meter. Some meters have a strainer covering the inlet and forming part of the meter. Such a strainer is shown at *b*, in Fig. 73. When a strainer does not form part of the meter, a separate strainer or fish trap should be used. In localities where the water is extremely dirty or carries large quantities of matter in suspension, a strainer, Fig. 74, formed of hinged brass strips, will be found more satisfactory than a perforated strainer, Fig. 75, owing to the ease with which the hinge strainer can be removed and cleaned.

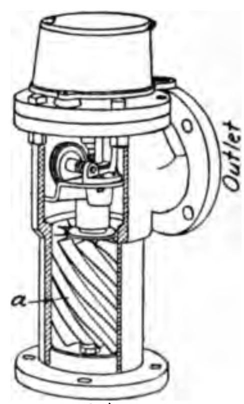


Fig. 72
Velocity Meter

Water meters should be located in an accessible place safe from frost. Where there is danger of hot water being forced backward through a meter a check valve should be placed in the supply pipe to protect the indurated rubber parts from being damaged by the hot water.

Special water meters, the working parts of which are made of bronze metal, are made for metering hot water. Venturi tube meters have no parts that can be affected by

the action of hot water, and may also be used for that purpose.

LOSS OF HEAD IN METERS.—There is considerable loss of head in small meters, but this loss grows less and less as the size of the meter increases, until above 6 inches in diameter it is almost a negligible quantity. In small house meters, however, it is a matter of considerable moment, as the loss of head requires twice the length of time to discharge a given quantity of water through a meter that would be required to discharge it merely through a pipe of the same length.

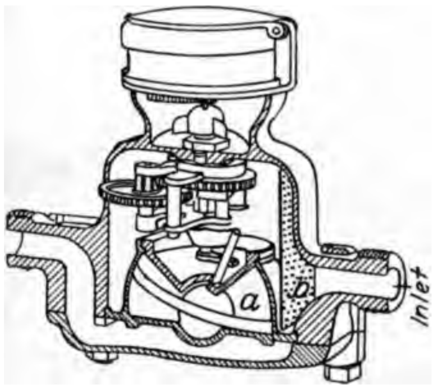


Fig. 73
Volume Meter

In Table XL will be found the relative lengths of time required for the flow of various quantities of water through meters of different sizes, and through the connections only. These tests were made on disk meters by the Bureau of Water, Chicago.

The tests were all made under a pressure of 30 pounds to the square inch.

WATER METER RATES.—The only sane and logical way to sell water is by meter rates, just as other commodities are sold. By this method waste will be prevented, each consumer pays for only what he actually uses, whereas under the price-per-house method, the careful householder pays for the extravagance of his careless town people.

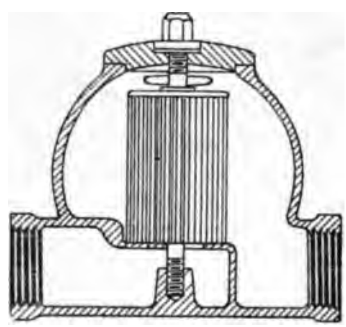


Fig. 74
Fish Trap

There are no good objections to selling water by meter rates. The only one worthy of considering is the fact of

great loss of head in passing through the meters. However, the saving affected by selling the water by measure instead of by time, will save the head necessary to force the water through the meters. Cost might be raised as an objection, but the cost per meter is slight, and pays for itself in a short time in water pumped, and wear and tear on the system. Once a meter is installed, it is good for a minimum of 20 years. It might require repairing during that time, as any other mechanical apparatus might, but counting repairs, the average life of a meter is perhaps a quarter century.

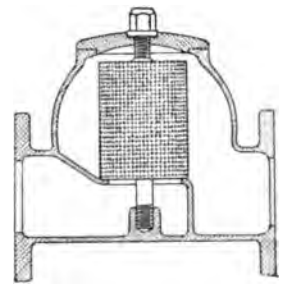


Fig. 75
Meter Strainer

Water is sold by gallon or cubic foot measure. The number of gallons a consumer is entitled to at different rates are given in Table XLI.

This table gives the number of gallons of water which a consumer is entitled to use daily for 365 days or one year, for the rate stated in the left hand column, at the price per 1000 gallons given in the heading.

TABLE XL. Loss of Head in Meters

Disk Meter, 1 inch stream	10 cubic feet of water	2 minutes, 18 seconds
Connection only	10 cubic feet of water	1 minute, 36 seconds
Disk Meter, 1½ inch stream	10 cubic feet of water	1 minute
Connection only	10 cubic feet of water	33 seconds
Disk Meter, 2 inch stream	10 cubic feet of water	40 seconds
Connection only	10 cubic feet of water	27 seconds
Disk Meter, 3 inch stream	100 cubic feet of water	2 minutes, 45 seconds
Connection only	100 cubic feet of water	1 minute, 58 seconds
Disk Meter, 4 inch stream	100 cubic feet of water	1 minute, 42 seconds
Connection only	100 cubic feet of water	1 minute 22 seconds
Disk Meter. 6 inch stream	100 cubic feet of water	1 minute. 24 seconds
Connection only	100 cubic feet of water	1 minute. 16 seconds

The cost of different quantities of water at different rates per 1000 gallons can be found in Table XLII.

The table is used in this way: At 5 cents per 1000 gallons, 400 cubic feet of water would cost 15 cents, at 6 cents per 1000 gallons, 18 cents; at 10 cents per 1000 gallons, 30 cents and at 30 cents per 1000 gallons, 90 cents.

WASTE OF WATER.—Where water is not sold by meter rates, more water is wasted than is used. It is, of course, not advisable to stint in the use of water, but when the daily consumption of water per person runs as high as 150 to 300

TABLE XLI. Water a Consumer is Entitled to Daily at Given Rates

No. of dollars paid annually	No. of gallons per day at 5c per 1000 gallons	No. of gallons per day at 10c per 1000 gallons	No. of gallons per day at 15c per 1000 gallons	No. of gallons per day at 20c per 1000 gallons	No. of gallons per day at 25c per 1000 gallons	No. of gallons per day at 30c per 1000 gallons	No. of gallons per day at 40c per 1000 gallons	No. of gallons per day at 50c per 1000 gallons
$ 1	54.8	27.4	18.2	13.7	10.9	9.1	6.8	5.5
2	109.6	54.8	36.5	27.4	21.9	18.2	13.7	10.9
3	164.4	82.2	54.7	41.1	32.8	27.4	20.5	16.4
4	219.2	109.6	73.0	54.8	43.8	36.5	27.4	21.9
5	274.0	137.0	91.3	68.5	54.8	45.6	34.2	27.4
6	328.8	164.4	109.6	82.2	65.7	54.8	41.1	32.8
7	383.6	191.8	127.8	95.9	76.7	63.9	47.9	38.3
8	438.4	219.2	146.1	109.7	87.6	73.0	54.8	43.8
9	493.1	246.6	164.4	123.4	98.6	82.2	61.6	49.3
10	547.9	273.9	182.6	137.0	109.6	91.3	68.4	54.8
20	1096	548	365	274	219	182	137	109.6
30	1644	822	548	411	329	274	205	164.4
40	2192	1096	730	548	438	365	274	219.2
50	2740	1370	913	685	548	456	342	274.0
60	3288	1644	1096	822	657	548	411	328.7
70	3836	1917	1278	959	767	639	479	383.5
80	4384	2191	1461	1095	876	730	548	438.3
90	4931	2465	1643	1232	986	822	616	493.1
100	5479	2739	1826	1369	1095	913	684	547.9
200	10959	5479	3653	2739	2191	1826	1370	1095.8
300	16438	8219	5479	4109	3287	2739	2055	1643.8
400	21918	10959	7305	5479	4383	3652	2740	2191.7
500	27397	13698	9132	6849	5479	4566	3424	2739.7
600	32876	16438	10958	8218	6575	5479	4109	3287.6
700	38356	19178	12784	9588	7671	6392	4794	3835.6
800	43835	21917	14610	10958	8766	7305	5479	4383.5
900	49315	24657	16437	12328	9862	8218	6164	4931.5
1000	54794	27397	18263	13698	10959	9132	6849	5479.4

gallons, fully one-sixth of it is wasted. Where water is charged for at the comparatively high rate of 15 cents per 1000 gallons, by meter, this will allow a daily consumption of water in a home of about 220 gallons for an annual tax of

TABLE XLII. Cost of Water per 1000 Gallons

Number of Cu. Feet	COST PER 1000 GALLONS 5 Cts.	6 Cts.	8 Cts.	10 Cts.	20 Cts.	25 Cts.	30 Cts.
	Cost for Quantity Given in First Column						
20	$0.007	$0.009	$0.012	$0.015	$0.030	$0.037	$0.045
40	0.015	0.018	0.024	0.030	0.060	0.075	0.090
60	0.022	0.027	0.036	0.045	0.090	0.112	0.135
80	0.030	0.036	0.048	0.060	0.120	0.150	0.180
100	0.037	0.049	0.060	0.075	0.150	0.187	0.224
200	0.075	0.090	0.120	0.150	0.299	0.374	0.449
300	0.112	0.135	0.180	0.224	0.449	0.561	0.673
400	0.150	0.180	0.239	0.299	0.598	0.748	0.898
500	0.188	0.224	0.299	0.374	0.748	0.935	1.122
600	0.224	0.269	0.359	0.449	0.898	1.122	1.346
700	0.262	0.314	0.419	0.524	1.047	1.309	1.571
800	0.299	0.350	0.479	0.598	1.197	1.496	1.795
900	0.337	0.404	0.539	0.673	1.346	1.683	2.020
1 000	0.374	0.449	0.598	0.748	1.496	1.870	2.244
2 000	0.748	0.898	1.197	1.496	2.992	3.740	4.488
3.000	1.122	1.346	1.795	2.244	4.488	5.610	6.732
4.000	1.496	1.795	2.393	2.992	5.984	7.480	8.976
5.000	1.870	2.244	2.992	3.740	7.480	9.350	11.220
6.000	2.244	2.692	3.590	4.488	8.976	11.220	13.464
7.000	2.618	3.141	4.189	5.236	10.472	13.090	15.708
8.000	2.992	3.590	4.787	5.984	11.968	14.961	17.953
9.000	3.366	4.039	5.385	6.732	13.464	16.831	20.197
10.000	3.74	4.488	5.984	7.480	14.961	18.701	22.441
20.000	7.48	8.976	11.968	14.961	29.992	37.402	44.882
30.000	11.22	13.46	17.95	22.44	44.88	56.10	67.32
40.000	14.96	17.95	23.94	29.92	59.84	74.80	89.77
50 000	18.70	22.44	29.92	37.40	74.80	93.50	112.20
60,000	22.44	26.92	35.90	44.88	89.76	112.20	134.64
70,000	26.18	31.41	41.89	52.36	104.72	130.90	157.08
80,000	29.92	35.90	47.87	59.84	119.68	149.61	179.53
90,000	33.66	40.39	53.85	67.32	134.64	168.31	201.97
100,000	37.40	44.88	59.84	74.80	149.01	187.01	224.41
200,000	74.81	89.76	119.68	149.61	299.22	374.02	448.82
300,000	112.20	134.64	179.53	224.41	448.83	561.03	673.24
400,000	149.61	179.53	239.37	299.22	598.44	748.05	897.66
500,000	187.01	224.41	299.22	374.02	748.05	935.06	1122.07
600,000	224.41	269.29	359.06	448.83	897.66	1122.07	1346.49
700,000	261.81	314.18	418.90	523.63	1047.27	1309.08	1570.88
800,000	299.22	359.06	478.75	598.44	1196.88	1496.10	1795.32
900,000	336.62	403.94	538.59	673.24	1346.49	1683.11	2019.73
1,000,000	374.02	448.83	598.44	748.05	1498.10	1870.12	2244.15

TABLE XLIII. Waste of Water

Head in Feet	Pressure	Diameter of Openings in Inches and Fractions of an Inch										
		1/8 in.	1/4 in.	3/8 in.	1/2 in.	5/8 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	1 3/4 in.	2 in.
20	8.66	75	300	720	1,260	1,920	2,760	4,920	7,380	11,100	15,120	19,740
40	17.32	112	450	960	1,800	2,760	3,960	6,720	10,920	15,720	21,360	27,960
60	25.99	135	540	1,200	2,160	3,480	4,800	8,580	13,380	19,200	26,220	34,260
80	34.65	155	620	1,380	2,460	3,840	5,580	9,840	15,480	22,260	30,300	39,540
100	43.31	172	690	1,560	2,760	4,320	6,240	11,040	17,280	24,900	33,900	44,280
120	51.98	195	780	1,680	3,000	4,740	6,840	12,120	18,960	27,240	37,440	48,480
140	60.64	201	816	1,860	3,300	5,100	7,320	13,020	20,160	29,460	39,080	52,320
150	64.97	210	840	1,920	3,420	5,280	7,620	13,560	21,180	30,480	41,460	54,120
175	75.80	225	900	2,040	3,660	5,700	8,220	14,640	22,800	32,880	44,940	58,560
200	86.63	240	960	2,220	3,900	6,120	8,760	15,600	25,020	35,880	47,880	62,580
235	101.79	270	1,080	2,460	4,320	8,280	11,160	17,100	26,760	38,520	52,260	58,460

twelve dollars. Assuming an average family of four persons, then each person has a daily allowance of about 55 gallons of water at the rate of 25 cents a month. This allowance is sufficient for all necessary purposes. For the bath in the morning, 20 gallons is sufficient. Then, assuming that each person will flush the closet four times daily, and that 5 gallons of water will be used at each flush, there still remains 15 gallons per person for general housework and laving.

If the price of water is 10 cents per 1000 gallons, then each person in a family of four is entitled to over 82 gallons of water daily for the annual water rate of twelve dollars.

Whatever the water rate may be, an allowance of 60 gallons per person each day would seem a sufficient amount for all necessary purposes, allowing even then a fair proportion for waste. When 200 and 300 gallons of water per capita are used daily by a large

population, the loss is not only the pumping of water, but the filtering of it, and the increased size of works necessary to supply the demand. Under such conditions, a plant with a capacity of from three to five times what is actually needed must be provided, and the cost of construction and the interest on the bonded indebtedness will add to the cost of the system. Besides, the larger the consumption of water, the larger the sewers necessary to carry away the waste; and, in these days of sanitation when communities purify their sewage before discharging it into lakes or streams, it imposes an additional burden for the construction and maintenance on the disposal works.

The great loss of water from leakage or running faucets can be judged from Table XLIII, which gives the number of gallons discharged per hour through various-sized ports under different pressures. As a summary it may be stated that an orifice the size of the lead in an ordinary pencil will, under sixty pounds pressure, discharge about 10 gallons an hour, 240 gallons a day, or 7,200 gallons a month—which is more than will be ordinarily used by a family of five people.

CHAPTER XVII

WATER HAMMER

If a column of water flowing through a pipe has its momentum suddenly arrested by closing a valve, the momentum of the moving water will produce an impulse upon the valve, and also upon the sides of the pipe. This impulse is called *water hammer.*

If the water were inflexible and incompressible as a bar of steel, the force of the impact would equal the weight of the column of water times the square of the velocity divided by twice the acceleration due to the force of gravity and would affect only the gate of the valve. As the water is flexible and slightly compressible, it exerts a pressure of equal intensity upon the sides of the pipe as well, which yield to the pressure and thus absorbs some of the energy of the moving column. The water, too, yielding to the pressure, slightly compresses, so that a short interval of time elapses before all of the energy of the moving water is brought to bear upon the gate and the sides of the pipe. The pipe being slightly elastic yields to the pressure and thus absorbs some of the energy, but it returns to its normal size again, and thus causes a reflex pressure wave back from the valve. This pressure wave passes back and forth in the pipe until the energy is absorbed in the friction of the water and iron molecules among themselves and against each other. Thus, a high pressure wave may pass back and forth through a pipe a dozen or more times, the intensity of each wave becoming less until it finally fades away to the dead level of the initial static pressure.

The intensity of a high-pressure wave caused by suddenly closing an ordinary ½-inch self-closing basin cock attached to the end of a 1½-inch pipe, is graphically shown in the accompanying diagrams.

In the diagrams, the line EF represents a zero or atmospheric pressure, the line *a* the static pressure of water in the pipes, that portion of the diagram above the level of

the line *a* indicates the increase of pressure due to water hammer, and that portion of the diagram below the level of the line *a* shows the drop of pressure below the static pressure due to the reflex pressure wave. Diagrams, Fig. 76 and Fig. 77 were obtained when no air chamber was on the water pipe. It will be noticed that in the diagram, Fig. 78, the wave is more uniform and symmetrical than in the

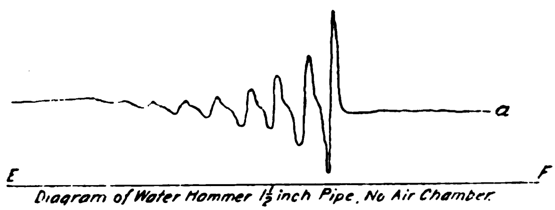


Fig. 76

others, and dies away gradually with a uniform intensity to the static pressure. It will be further observed that although there are the same number of pulsations in this as in the other diagrams, they are of less intensity both above and below the static pressure line. That was due to the fact that an air chamber was used in this experiment. The experiment from which diagram, Fig. 79, was obtained was conducted with the air chamber filled with water. Such a condition would be equivalent to having no air chamber on

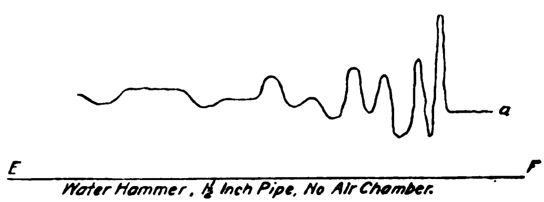


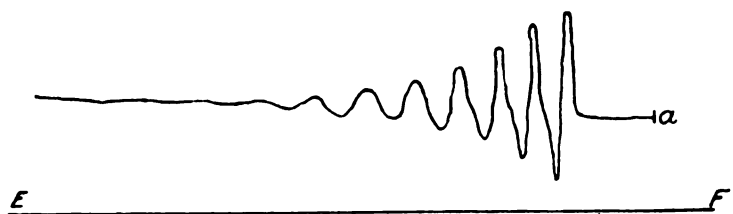
Fig. 77

the pipe, and the results obtained under those two conditions were very similar.

The conditions under which the experiments were made that produced the foregoing diagrams are given in Table XLIV, which shows intensity, duration and number of pressure waves produced in a 1½-inch pipe by suddenly

closing a ½-inch self-closing basin cock. Approximate time of closing cock 1/100 of a second.

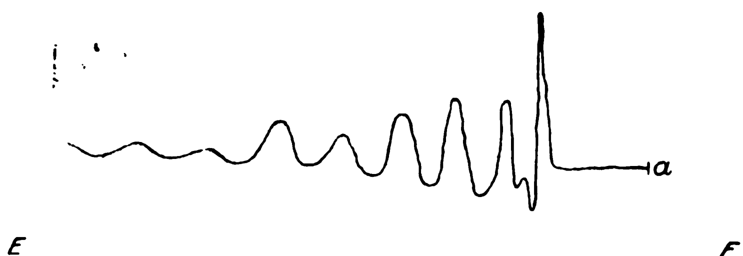
The intensity of a high pressure wave caused by suddenly arresting the momentum of a column of water in a 2-inch pipe by shutting a quick-closing gate valve of the full



Water Hammer Diagram: 1½ inch Pipe, Air Chamber.

Fig. 78

size of the pipe, is graphically shown by the diagram, Fig. 80. It will be noticed that this diagram records a vacuum of about 15 pounds due to the reflex wave. This is supposed by the experimenters* to be an error. It is believed by them that the momentum of the moving parts of the recording apparatus carried the line that much below



Water Hammer Diagram; 1½ inch Pipe, Water Chamber.

Fig. 79

the line of atmospheric pressure E F, and that likewise it recorded a maximum pressure of 15 pounds in excess of the pressure actually produced. Allowance should therefore be made for the error.

A number of experiments were made with the 2-inch

*Two students of Cornell College acting under the direction of Professor Carpenter.

pipe and quick-closing lever-handle gate valve, to determine the intensity of the water hammer under different velocities. Some of the experiments were made with an air chamber of 40 cubic inches capacity, attached to the water pipe near the valve. Some of them were made with an air chamber of 320 cubic inches capacity attached, and still others were made without an air chamber. From the results obtained by the experiments, the diagram, Fig. 81, was plotted.

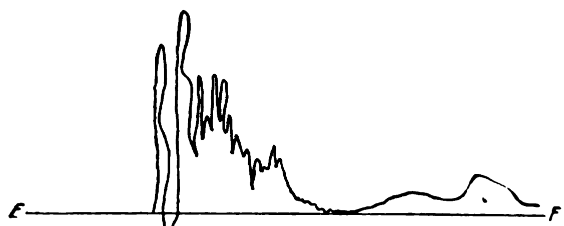


Diagram Water Hammer. 2inch Pipe. 30 # Static Pressure.

Fig. 80

In this diagram the curves all start at the point of static pressure in the pipe, as that is the initial pressure. The results of the experiments plotted on the diagrams show the high pressure that can be produced in a pipe by abruptly stopping the flow of water, even when the velocity and pressure are comparatively low. It also shows the value of air

TABLE XLIV. Intensity of Water Hammer

General Data	No Air Chamber		Air Chamber	Air Chamber Filled with Water
	Fig. 73	Fig. 74	Fig. 75	Fig. 76
Static pressure	29.5	28.5	27.5	28.
Number of distinct blows	8.	9.	9.	9.
Maximum pressure	72.5	69.0	61.5	76.0
Minimum pressure	2.5	16.	10.	9.
Time pulsations continue	0.8 sec.	1.2	0.8	1.1 sec.
Pressure at end of one second	36.	36.	31.5	36.
Ratio of increase of pressure	2.47	2.56	2.15	2.70

Note: Table and diagrams from "Transactions of American Institute of Mechanical Engineers," Vol. XV, page 510.

chambers on water supply pipes and the necessity for using slow-closing cocks in practice, particularly when the pressure of the water is high.

With a static pressure of 30 pounds per square inch and a velocity of 8 feet per second, the maximum pressure due to water hammer when no air chamber was used was 320 pounds to the square inch; an increase in pressure of 290 pounds or an ultimate pressure of almost eleven times

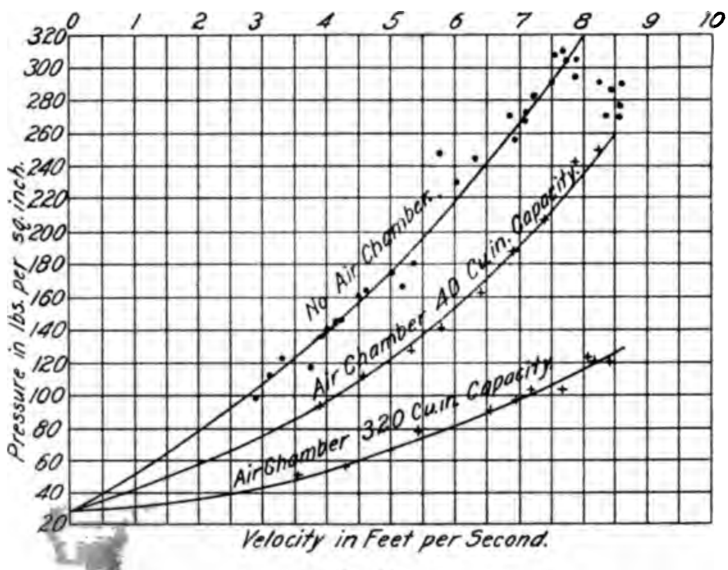


Fig. 81
Chart of Water Hammer

the initial pressure. At a velocity of 4 feet per second with all of the other conditions unchanged, the maximum pressure was about 135 pounds per square inch, or an ultimate pressure of 4½ times the initial pressure. With an air chamber of 40 cubic inches capacity and a velocity of 8 feet per second, the maximum pressure was about 230 pounds, or an increase of 200 pounds above static.

When an air chamber of 320 cubic inches capacity was used, and with a velocity of 8 feet per second, the maximum pressure produced was less than that produced with a velocity of 3.5 feet per second when no air chamber was used.

It will be observed, however, that the experiment conducted with the ½-inch self-closing basin cock more nearly approaches the condition found in practice. In those experiments the ultimate pressure was equal to about three times the initial pressure, while in a water supply system provided with adequate air chambers at suitable points, and fitted with slow-closing faucets, the maximum pressure due to water hammer should never exceed double the static pressure.

No satisfactory formula has yet been advanced for calculating the force of impact due to water hammer. The following example, however, will serve to illustrate arithmetically the severe strain that a water pipe is sometimes subjected to when a bibb is closed.

If a 2-inch pipe 100 feet long, and subject to the pressure due to a head of 100 feet, has a ¾-inch bibb open at its extreme end, the velocity* of the spouting water will be 65.28 feet per second; as the area of the 2-inch pipe is 7.12 times the area of a ¾-inch bibb, the velocity of water in the 2-inch pipe will be $\frac{65.28}{7.12} = 9.16$ feet per second. The weight of the column of water in motion, from which is derived the force of impact, is $\frac{\text{length of pipe} \times \text{area of pipe}}{\text{1 cubic foot}} =$

$$\frac{\text{1,200 inches} \times \text{3.14 square inches}}{\text{1,728 cubic inches}} = 2.18 \text{ cubic feet,}$$

which, multiplied by 62.5, the weight of one cubic foot of water, gives 136.25 pounds, the weight of the moving column. The $\frac{\text{velocity}^2}{2} \times \frac{\text{weight}}{\text{gravity}} = \frac{9.16^2}{2} \times \frac{136.25}{32.16} =$ 177.45 foot pounds, the force with which the moving column of water would strike the bibb, if water were incompressible. As a matter of fact, however, water is slightly com-

*By the formula $48\sqrt{\frac{hd}{L + 54d}}$

pressible, therefore the actual force of impact would be slightly less than this value.

The force of impact to a great extent is dependent upon the time consumed in closing the bibb. Thus, if the force of impact due to closing the bibb in one second = 174.45 pounds, the force due to closing it in ½ second would equal 354.9 pounds, and to closing it in ¼ second, 532.35 pounds.

AIR CHAMBERS.—An air chamber is a tank, vessel or chamber so attached to a pipe that the confined air cannot escape, and so located that it will receive the initial impact and thus absorb the momentum of a column of water when it is suddenly brought to rest. When properly designed and located for the purpose, air chambers also provide expansion space for water in exposed pipes; the water expands upon freezing and might burst the pipes if provision were not made for its expansion.

The value of air chambers for water supply systems has never been fully appreciated, nor the sizes required under varying conditions fully understood; hence, in the exceptional cases where air chambers are installed, they are usually so small as to be of no practical value.

To wholly absorb the momentum of a moving column of water, an air chamber should be proportioned to the quantity of water in motion and the static pressure due to the head. For instance, it would require a larger air chamber for a 4-inch pipe 100 feet long than for either a 4-inch pipe 50 feet long or for a 1-inch pipe 100 feet long, the pressure in all cases being the same; and it would require a larger air chamber for a 4-inch pipe 100 feet long under 100 pounds pressure than for the same size and length of pipe under 50 pounds pressure. This is due to the compressibility of air, which when the temperature remains unchanged varies inversely as the absolute pressure.* That is to say, if the pressure on air in a vessel be increased to twice the atmospheric pressure the air will be compressed to ½ its original volume. If the pressure be increased to 3 atmospheres,

*Absolute pressure equals gauge pressure plus atmospheric pressure, which at sea level is taken as 14.7 pounds.

reckoning from absolute, the air will be compressed to 1/3 its original volume. If the pressure be increased to 4, 5, 6, 8 or 10 atmospheres, the air will be compressed respectively to ¼, 1/5, 1/6, ⅛ or 1/10 its original volume. Hence, if an air chamber containing 25 cubic feet were used in connection with a water supply system subject to a pressure of 11 atmospheres absolute or 147 pounds gauge pressure, the air in the chamber would be compressed to 1/10 its original bulk or to 2.5 cubic feet. The size of air chamber required when the diameter and length of pipe and the static pressure are known, can be approximately determined by the following empirical rule:

Rule—Multiply the quantity of moving water in cubic feet by the coefficient of pressure in Table XLV. The product will be the contents in cubic feet of the air chamber.

EXAMPLE—What size air chamber will be required for a pipe 4 inches diameter and 100 feet long under a static gauge pressure of 58 pounds per square inch?

SOLUTION— $\frac{1200 \times 12.57}{1728} = 8.7 \times 1.18 = 10.26$ cubic feet.—Answer.

TABLE XLV. Coefficients of Pressure

Absolute Pressure	Gauge Pressure	No. of Atmospheres		Coefficient of Pressure	Portion of original bulk to which air will be compressed
		Abso.	Gauge		
29.4	14.7	2	1	.28	½
44.1	29.4	3	2	.59	1/3
58.8	44.1	4	3	.88	¼
73.5	58.8	5	4	1.18	1/5
88.2	73.5	6	5	1.41	1/6
102.9	88.2	7	6	1.76	1/7
117.6	102.9	8	7	2.05	⅛
132.3	117.6	9	8	2.35	1/9
147.	132.3	10	9	2.65	1/10
161.7	147.	11	10	2.94	1/11
176.4	161.7	12	11	3.24	1/12

The coefficients of pressure in the foregoing table are arbitrarily obtained by allowing .2 for each 10-pound gauge pressure in the water mains. Therefore, the rule to deter-

mine the size of air chambers can be expressed as a formula, thus:

$s = qc$, in which s = size of air chamber in cubic feet, q = quantity of moving water in cubic feet, c = coefficient of pressure which is .2 for each 10-pounds gauge pressure.

EXAMPLE— What size air chamber will be required for a pipe 2 inches diameter and 50 feet long under a static gauge pressure of 100 pounds per square inch?

SOLUTION—Area of 2-inch pipe = 3.36 inches. Coefficient of pressure equals $.2 \times 10 = 2.0$; then $\frac{600 \times 3.36}{1728} \times 2 = 2.33$ cubic feet.—Answer..

Water at atmospheric pressure will absorb 4 per cent. its bulk of air. If the pressure of water be increased it will absorb 4 per cent. its bulk for each additional atmosphere of pressure. Hence, if the pressure in a system is 150 pounds, water will absorb 11×4 per cent. = 44 per cent. its bulk of air, and the air will be soon absorbed from the air chambers; provision should therefore be made to recharge them when the air is exhausted. A pet cock in small air chambers and a stop cock in large ones very satisfactorily serve this purpose.

In arranging air chambers they should be so located that the energy or momentum of the column of water can be expended directly upon the air confined in them. By so locating them they receive the initial shock of the moving column of water and absorb most of its energy, thereby minimizing the intensity and reducing the number of high pressure waves. Air chambers should also be placed on the house side of water meters or other delicate apparatus that might be injuriously affected by water hammer. Under all conditions air chambers should be placed in a vertical position and never at the side or bottom of a pipe. If so placed, they will shortly fill with water and become useless.

Air chambers placed above faucets are not so liable to lose their air by absorption, because when passing the inlet to an air chamber so placed, the pressure is greatly reduced, and if the water at static pressure is saturated with air, the air will be released by the reduction in pressure and some of it will rise and recharge the air chambers.

Air chambers should be provided on all distributing drums, on the discharge pipes from power pumps, on the house side of delicate apparatus, like water meters, and on the supplies to fixtures. A very satisfactory type of air chamber for basin or other fixture supply is shown in Fig. 82. The enlarged chamber on this supply provides ample capacity for small pipes of moderate length and being placed directly on the supply pipe it receives the initial impact of the moving column of water.

Air Locks in Plumbing

THEORY OF AIR LOCKS.—The manner in which water may be locked in a pipe so it will not flow, even though the mouth of the pipe is considerably below the level of the source of water, can be seen in Fig. 83, which shows conventionally the operation of an air-lock. Assume that the tank and piping which were empty, are slowly filled with water. As the water rises in the tank, it will rise likewise in the vertical pipe *a* until it reaches the bend at the top, when it will overflow into the pipe *b* and seal the bend at the bottom. Water continuing to flow into the tank rises the level, thereby increasing the head or pressure, and the overflow of water will rise in pipe *c*, compressing the air in pipe *b* as it does so. From *c* the water will overflow into pipe *d*, sealing the bend at the bottom, and rise in the pipe *e* a certain distance, when it refuses to rise any higher or overflow, even though the outlet of the pipe *e* is below the level of the hydraulic gradient to which, according to the law of water seeking its own level, it ought seemingly to rise. The explanation is, the confined air in the pipes is so locked that instead of the several columns of water in the different pipes balancing one another, they are all pressing through the intermediary of the air, on the top of the water in pipe *a*. That being so, it is as though the several

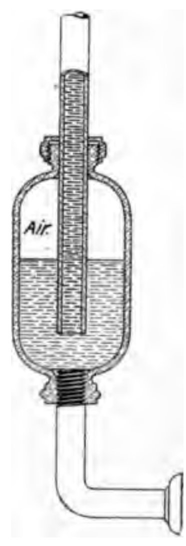


Fig. 82
Air Chamber

columns of water were piled on top of one another. Owing to the compressibility of air, the water would rise to a certain height in all the legs; but, the differences between levels are the heads to be considered. For instance, there is a depth of three feet of water in the tank. In the pipe *a*, on the other hand, there is a head of 18 inches to offset half the depth of water in the tank. The difference between the levels of the water in legs *b* and *c* is 14 inches, and between *d* and *e* 4 inches; and then 14 + 4 inches = 18 inches on top of the 18 inches of the column of water in *a* would give a head of water equal to that in the tank, and one column would balance the other so no head would be left to cause a flow. The water in the pipe is then air-bound.

Trouble is never caused from air locks in high pressure work, but in domestic installation where the head of water

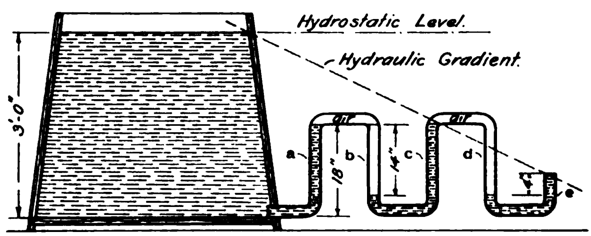


Fig. 83
Air Lock in Water Pipe

is low it is a common cause of annoyance, often preventing water reaching the fixtures, particularly from the hot water tank. Double trapping of waste pipes will likewise cause an air lock in the discharge from fixtures, the pipe flowing perfectly free when under the force of a pump or stream of water, but soon air-locking when only a couple inches of water are allowed to run into the waste pipe.

In buildings where a storage tank is used, and fixtures are located on the same floor as the storage tank, but some distance away, the water sometimes becomes air-bound so it will not flow at the fixtures on the same floor as the storage tank, particularly at the hot water faucet. This will only occur if the hot water pipe dips down from the boiler to the cellar or basement before rising to the fixtures, and

no relief pipe is provided. The reason is, when water is heated, its capacity to absorb or hold air is lowered, and air bubbles released from the water collect in the top of the hot water loop from the boiler, displacing the air and forming an air-lock. The remedy is to run a relief pipe from the hot water pipe above the boiler to above the storage tank to allow the air to escape, or else in low pressure work, give all hot water pipes a rise from the boiler to the fixtures. Under such conditions, never trap them by extending them to the cellar or basement.

Trouble from air lock is found most frequently in cottages of two stories in height, with no attic overhead for a storage tank, so the house tank has to be located on the second floor in an unused room near the ceiling. The difference in level between the bottom of the tank and the faucets to a lavatory, or the supply to an overhead closet tank, is so slight, that but little head remains to force the water to those fixtures. If, then, they happen to be located at considerable distance from the house tank and hot-water boiler, there is not only the friction of the pipes to overcome, but the additional danger of air-locks, particularly when the hot-water pipe from the boiler dips down to the cellar and is run along the cellar ceiling to the point where it again rises to the fixtures. If the hot water pipe is run along the first-floor ceiling to the fixture risers, there is less danger of air-locks, for the instant a faucet above that level is opened, the air will escape from the faucet, thereby allowing the pipe to fill with water.

CHAPTER XVIII

WATER SUPPLY PIPES

QUALITY AND STRENGTH OF PIPES.—The safe working pressures that pipes will sustain depends upon the materials of which they are made and the thickness of their walls. The ultimate stress that a material will sustain before rupture ensues, is known as the tensile strength of that material and is the resistance offered to its fibre being pulled apart.

There are four notable stresses to which a pipe is subjected before rupture ensues; they are: *safe working pressure, elastic limit, absolute strength* and *bursting stress.* The elastic limit of a seamless drawn pipe is generally about one-half its absolute strength; in the case of cast-iron and lead pipes, however, the elastic limit is much lower, owing to the low coefficients of elasticity for these metals. In water supply systems where the pressure is fairly constant and free from water hammer one-half the elastic limit of seamless pipes can be taken as their safe working strength. If the supply system is not properly fitted with air chambers and is equipped with quick-closing faucets, the static pressure should not exceed one-third of the elastic limit of the pipe. In the case of metals with a low coefficient of elasticity, the safe working pressure for dead loads can be taken as one-fourth, and for live loads as one-sixth of the elastic limit of the pipe. This allowance provides a suitable factor of safety for the excessive pressures inseparable from most water supply systems.

A dead load is one that is fairly constant in pressure; a live load is one that fluctuates in pressure or is seriously affected by water hammer.

If a pipe is subjected to a great internal pressure, but of not sufficient intensity to strain it beyond its elastic limit, the pipe will yield to the pressure, but will immediately return to its normal condition upon being released from the pressure. If, however, the elastic limit is exceeded, the

pipe will yield to the pressure and assume a new shape which it will retain after the pressure is removed.

When the pressure in a pipe is sufficient to strain it beyond the elastic limit the pipe yields to the pressure and the alteration of form becomes greater and greater until the absolute strength of the pipe is reached. Any additional pressure will then cause a bursting strain and rupture the pipe.

STRENGTH OF LEAD PIPE.—The pressure at which lead pipe will burst can be found by the following rule:

Rule—Multiply the tensile strength of the metal in pounds per square inch by twice the thickness of the pipe in inches, and divide the product by the internal diameter of the pipe in inches. The result will be the pressure at which the pipe will burst.

Expressed as a formula:

$p = \frac{2000\,t\,2}{d}$, in which p = bursting pressure in pounds per square inch, 2000 = tensile strength of the metal in pounds per square inch, t = thickness of the metal in inches, d = internal diameter of pipe in inches.

EXAMPLE—What is the bursting pressure of a lead pipe 3 inches in diameter and .5 inch thick?

SOLUTION— $\frac{2000 \times .5 \times 2}{3} = \frac{2000}{3} = 666.6$ pounds pressure.

CORROSION OF LEAD PIPE.—Lead pipe should be protected from contact with concrete, particularly if cinders are used for the aggregate, as they form a particularly destructive combination. Oak also has a corrosive effect on lead. When necessary to imbed sheet lead or lead pipe in cinder concrete, or place them in contact with oak, the lead should be protected with a layer of tar paper, or a heavy coat of asphaltum.

The maximum thickness of a lead pipe that will burst under a given head of water can be found by the following rule:

Rule—Multiply the pressure of water in pounds per square inch by the internal diameter of the pipe in inches, and divide the product by twice the tensile strength of the

metal in pounds per square inch. The result will be the thickness of the metal in inches.

Expressed as a formula:

$t = \frac{p\,d}{4000}$, in which t = thickness of the metal in inches, p = bursting pressure in pounds per square inch, d = internal diameter of pipe in inches, 4000 = constant; two tensile strengths.

EXAMPLE—When the internal diameter of a pipe is 3 inches and the pressure at which it will burst is 667 pounds per square inch, what is the minimum thickness of the metal that will withstand the pressure?

SOLUTION— $\frac{667 \times 3}{2000 \times 2} = \frac{2001}{4000} = .5$ inch

When the pressure of water is known the thickness of a lead pipe that will safely sustain that pressure can be found by the following rule:

Rule—Multiply the pressure in pounds per square inch by the coefficient of the factor of safety; multiply that product by the internal diameter of the pipe in inches, and divide the product by twice the tensile strength of the metal in pounds per square inch. The result will be the thickness of the metal in inches.

The coefficients of the factors of safety are: for a live load 6 and for a dead load 4.

Expressed as a formula:

$t = \frac{p\,c\,d}{4000}$, in which t = thickness of the metal in inches, p = pressure in pounds per square inch, c = coefficient of factor of safety, d = internal diameter of the pipe in inches, 4000 = constant; two tensile strengths.

EXAMPLE— Find the thickness of metal required for a 3-inch pipe to safely stand a pressure of 167 pounds per square inch, (*a*) when the system is equipped with self-closing faucets and no air chambers, (*b*) when compression cocks are used and a suitable air chamber provided.

SOLUTION (*a*) $\frac{167 \times 6 \times 3}{2000 \times 2} = \frac{3006}{4000} = .75$ inch thick

(*b*) $\frac{167 \times 4 \times 3}{2000 \times 2} = \frac{2004}{4000} = .5$ inch thick

SIZE AND DIMENSIONS OF LEAD PIPE.—Dimensions and weights of stock sizes of lead pipe can be found in Table XLVI. The sizes given are *inside* diameters.

TABLE XLVI. Sizes and Weights of Lead Pipes

Calibre	Weight per Foot		Calibre	Weight per Foot	
	Pounds	Ounces		Pounds	Ounces
3-32-inch Tubing	....	1 1/4	7/8-inch Medium	3	....
1/8-inch Tubing	....	3	Strong	3	8
3/16-inch Tubing	....	4	1 -inch Aqueduct	1	8
1/4-inch Tubing	....	6	Ex. Light	1	....
Fish Seine	....	15	Light	2	8
3/8-inch Aqueduct	....	8	Medium	3	4
Ex. Light	....	9	Strong	4	....
3/8-inch Light	....	12	Ex. Strong	4	12
Medium	1	....	Ex. Ex. Strong	5	8
Strong	1	8	1 1/4-inch Aqueduct	2	....
Ex. Strong	2	....	Ex. Light	2	8
1/2-inch Aqueduct	....	10	Light	3	....
Ex. Light	....	12	Medium	3	12
Light	1	....	Strong	4	12
Medium	1	4	Ex. Strong	6	....
Strong	1	12	Ex. Ex. Strong	6	12
A. A	2	....	1 1/2-inch Aqueduct	3	....
Ex. Strong	2	8	Ex. Light	3	8
Ex. Ex. Strong	3	....	Light	4	....
5/8-inch Aqueduct	....	12	Medium	5	....
Ex. Light	1	4	Strong	6	....
Light	1	12	Ex. Strong	7	8
Medium	2	....	Ex. Ex. Strong	9	....
Strong	2	8	1 3/4-inch Ex. Light	3	12
Ex. Strong	3	....	Light	4	8
Ex. Ex. Strong	3	8	Medium	5	8
3/4-inch Aqueduct	1	....	Strong	6	8
Ex. Light	1	8	Ex. Strong	8	....
Light	2	....	2 -inch Waste	3	....
Medium	2	4	Ex. Light	4	....
Strong	3	....	Light	5	....
Ex. Strong	3	8	Medium	7	....
Ex. Ex. Strong	4	....	Strong	8	....
7/8-inch Aqueduct	1	8	Ex. Strong	9	....
Ex. Light	2	....	Ex. Ex. Strong	10	8
Light	2	8			

WROUGHT IRON AND STEEL PIPES.—Wrought pipes and steel pipes are made in various sizes and weights and may be had plain, tar coated or galvanized. The weights of wrought pipe are designated as standard, extra strong and double extra strong; standard weight pipe being the weight most commonly used in plumbing installations. Wrought pipe is sometimes classified as butt-welded and lap-welded. In the manufacture of butt-welded pipe the edges of the metal that forms the pipe are butted together and welded. In the manufacture of lap-welded pipe the edges are first beveled and then lapped and welded to smooth interior and exterior finishes. Butt-welded pipes are not as strong in the seam as lap-welded pipes and are made only in small sizes of standard weight.

Wrought pipes are galvanized by cleaning them with acid and then immersing them in a bath of molten zinc or tin and zinc. This process makes the pipe a little more brittle than plain pipe, but it lengthens its life by preserving it from corrosion. Furthermore, galvanizing protects the water that flows through the pipe from rust discoloration, which would render the water unfit for domestic and for most manufacturing purposes.

The safe working pressure for wrought pipe does not depend altogether upon the thickness of the walls of the pipe and the tensile strength of the metal, but is governed by the strength of the seams and the method of connecting different lengths of pipe. For instance, a 1½-inch butt-weld standard pipe is tested to a pressure of 600 pounds and will safely sustain a working pressure of 300 pounds to the square inch, while a 1½-inch lap-weld standard pipe is tested to a pressure of 1000 pounds and will safely withstand a working pressure of 500 pounds per square inch.

The rule may be broadly stated that small sizes of standard weight pipe, ranging from ⅛ to 1½-inch diameters, are butt-welded and tested to 600 pounds pressure. Such pipes will safely sustain a working pressure of 300 pounds per square inch. All larger sizes of standard weight pipes are lap-welded. They are tested to 1000 pounds, and will safely sustain a working pressure of 500

TABLE XLVII. Dimensions of Standard Wrought Iron Pipe

Diameter			Thickness	Circumference		Transverse Areas			Length of Pipe per Sq. Foot of		Length of Pipe containing one Cubic Foot	Nominal Weight per Foot	Number of Threads per Inch of Screw
Nominal Internal	Actual External	Approximate Internal Diameter		External	Internal	External	Internal	Metal	External Surface	Internal Surface			
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet	Feet	Feet	Lbs.	
1/8	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
1/4	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
1/2	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
3/4	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.49	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8

Extra strong pipe is always shipped without threads or couplings, unless otherwise specified.

TABLE XLVIII. Dimensions of Extra Strong Wrought Iron Pipe

Diameter			Thickness	Nearest Wire Gauge	Circumference		Transverse Areas			Length of Pipe per Sq. Foot of		Nominal Weight per Foot
Nominal Internal	Actual External	Approximate Internal Diameter			External	Internal	External	Internal	Metal	External Surface	Internal Surface	
Inches	Inches	Inches	Inches	No.	Inches	Inches	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet	Feet	Lbs.
1/8	.405	.205	.1	12½	1.272	.644	.129	.033	.086	9.433	18.632	.29
1/4	.54	.294	.123	11	1.696	.924	.229	.068	.161	7.075	12.986	.54
3/8	.675	.421	.127	10½	2.121	1.323	.358	.139	.219	5.657	9.07	.74
1/2	.84	.542	.149	9	2.639	1.703	.554	.231	323	4.547	7.046	1.09
3/4	1.05	.736	.157	8½	3.299	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	3	4.131	2.988	1.358	.71	.648	2.904	4.016	2.17
1¼	1.66	1.272	.194	6½	5.215	3.996	2.164	1.271	.893	2.301	3.003	3.
1½	1.9	1.494	.203	6	5.969	4.694	2.835	1.753	1.082	2.01	2.556	3.63
2	2.375	1.933	.221	5	7.461	6.073	4.43	2.935	1.495	1.608	1.975	5.02
2½	2.875	2.315	.28	2	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.5	2.892	.304	1	10.996	9.085	9.621	6.935	3.052	1.091	1.328	10.25
3½	4.	3.358	.321	0	12.566	10.549	12.566	8.856	3.71	.955	1.137	12.47
4	4.5	3.818	.341	0	14.137	11.995	15.904	11.449	4.455	.849	1.	14.97
4½	5.000	4.280	.360	00	15.708	13.446	19.635	14.387	5.248	.764	.748	18.22
5	5.563	4.813	.375	00	17.477	15.120	24.306	18.193	6.12	.687	.793	20.54
6	6.625	5.75	.437	000	20.813	18.064	34.472	25.967	8.505	.577	.664	28.58

pounds per square inch. Extra strong lap-welded pipes when joined with extra heavy couplings will safely sustain a working pressure of 1000 pounds per square inch.

Most of the pipe now sold as wrought iron is in fact made of steel. It cannot easily be distinguished from wrought iron pipe, and for most purposes is equally as good.

In Tables XLVII, XLVIII and XLIX the weights and dimensions of standard, extra strong and double extra strong pipes can be found.

These tables of dimensions and capacity of pipes are from 1/8 to 6 inches inclusive. Larger sizes are so seldom used by plumbers that they have been omitted. The number of threads to the lineal inch can be found in table of standard wrought pipe. The number of threads is the same in the corresponding sizes of extra strong and double extra strong pipe.

MERCHANT AND FULL-WEIGHT PIPES.—In addition to the classification of pipes as standard, extra strong and double extra strong, there is a distinction made among manufacturers and dealers between pipes which run within 5 per cent. of specified weights and those which fall below the 5 per cent. limit. Pipes which are within 5 per cent. of card weights are known as *full weight pipes*, while those which fall below the 5 per cent. limit are known as *merchant pipes*. There is no difference in the materials used for the different grades or sizes of pipes, and so far as the full weight and merchant pipes are concerned, they are subjected to the same tests and receive equal care and inspection as to welding and material. Merchant pipe is from 2 to 3 per cent. lighter than full weight pipe, and will consequently vary as much as 8 per cent. from card weights. However, for most purposes it is sufficiently strong, but when the maximum weights and strengths are wanted, full-weight pipe should be specified.

Brass Pipes

Brass pipes of iron-pipe sizes are made in stock lengths of 12 feet, although special lengths can be had to order. The lengths are seamless drawn, can be had plain, polished,

TABLE XLIX. Dimensions of Double Extra Strong Wrought Iron Pipe

Diameter			Thickness	Nearest Wire Gauge	Circumference		Transverse Areas			Length of Pipe per Sq. Foot of		Nominal Weight per Foot
Nominal Internal	Actual External	Approximate Internal Diameter			External	Internal	External	Internal	Metal	External Surface	Internal Surface	
Inches	Inches	Inches	Inches	No.	Inches	Inches	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet	Feet	Lbs.
½	.84	.244	.298	1	2.639	.766	.554	.047	.507	4.547	15.667	1.7
¾	1.05	.422	.314	1	3.299	1.326	.866	.139	.727	3.637	9.049	2.44
1	1.315	.587	.364	00	4.131	1.844	1.358	.271	1.087	2.904	6.508	3.65
1¼	1.66	.885	.388	00	5.215	2.78	2.164	.615	1.549	2.304	4.317	5.2
1½	1.9	1.088	.406	000	5.969	3.418	2.835	.93	1.905	2.01	3.511	6.4
2	2.375	1.491	.442	0000	7.461	4.684	4.43	1.744	2.686	1.608	2.561	9.02
2½	2.875	1.755	.560	9/16—	9.032	5.513	6.492	2.419	4.073	1.328	2.176	13.68
3	3.5	2.284	.608	⅝—	10.996	7.175	9.621	4.097	5.524	1.091	1.672	18.56
3½	4.	2.716	.642	⅝ +	12.566	8.533	12.566	5.794	6.772	.955	1.406	22.75
4	4.5	3.136	.682	11/16—	14.137	9.852	15.904	7.724	8.18	.849	1.217	27.48
4½	5.000	3.564	.718	¾	15.708	11.197	19.635	9.976	9.659	.764	1.000	32.53
5	5.563	4.063	.75	¾	17.477	12.764	24.306	12.965	11.34	.687	.940	38.12
6	6.625	4.875	.875	⅞	20.813	15.315	34.472	18.666	15.806	.577	.784	53.11

Double extra strong pipe is always shipped without threads or couplings, unless otherwise specified.

TABLE L. Sizes and Weights of Seamless Brass Tubing

Iron Pipes, Size, Inches	⅛	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6
Weights per Lineal Foot	.25	.43	.62	.90	1.25	1.70	2.50	3.00	4.00	5.75	8.30	10.90	12.70	15.75	18.31

or nickel-plated and tempered hard, soft or medium; the medium temper, sometimes called regular temper, is just sufficiently annealed to make it suitable for plumbing and steam work. Seamless brass pipes of iron pipe sizes are not made larger than 6 inches in diameter. Up to that size they may be had in standard and extra heavy weights, which correspond in safe working pressures with standard and extra heavy wrought pipes.

The sizes and weights of iron-pipe sizes of brass pipes may be found in Table L.

Brass fittings should correspond in finish with the pipes they join. The fittings are similar in pattern to beaded malleable iron fittings.

IRON PIPE FITTINGS.—Threaded fittings for small sizes of wrought iron pipes are usually made of malleable iron, and have a bead cast around the outlets to strengthen them and prevent their splitting when being screwed on a pipe. For the larger sizes of wrought pipes, cast iron fittings, similar to those used for steam fittings, are generally used.

CHAPTER XIX
COCKS AND VALVES

GATE VALVES.—The two principal types of valves used to stop the flow of water in water supply systems are gate valves and globe valves. A gate valve is shown in section in Fig. 84. It is operated by raising and lowering the double-faced wedge-shaped gate, *a*. When the valve is closed, the two faces of the gate are tightly pressed against the seats, *b*, *b*, thus effecting a double seal. The chief advantages of a gate valve are its tight seal and full size straightway opening, which offers no greater resistance to the flow of water than would an ordinary pipe coupling or other fitting of equal length. Either end of this make of gate valve may be used as the inlet, although there are some makes of gate valves that are single seated or have only one gate face. Such valves should be screwed on a pipe with the valve face to the pressure.

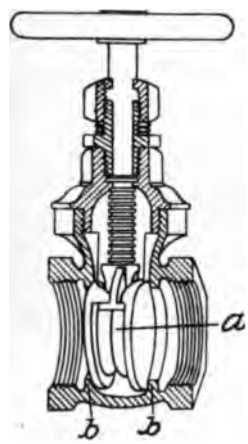


Fig. 84
Gate Valve

GLOBE VALVES.—The type of valve most commonly used for water supply systems is the globe valve, shown in section in Fig. 85. This type of valve has an inlet and outlet end, and a valve disk, *a*, that closes against the pressure. The valve is operated by lowering the disk, *a*, until it presses firmly and evenly on the valve seat, and thus cuts off the flow of water. By turning the valve stem to the left, thus raising the valve disk from its seat, the water is turned on. Instead of an interchangeable soft disk, as shown in the illustration, some globe valves have a brass disk that closes on a brass seat. Such valves seldom remain water tight more than a few months and cannot be repaired as easily and inexpensively as can soft disk valves; therefore, it is a

matter of economy to use soft seat valves. The principal objections to the use of globe valves are, that the opening, *c*, through the seat of the valve is never the full area of the corresponding size of pipe, and therefore not only restricts the flow but offers considerable frictional resistance; furthermore, the opening is not straight-way, consequently it offers additional frictional resistance to the flow of water. In addition to the frictional resistance and loss of flow caused by globe valves, they also, when placed on horizontal pipes, form traps that keep the pipes half full of water when the pipes are drained. This is shown by the part, *d*, which shows the depth of water retained by a globe valve when the water is drawn off from the system. This latter objection, however, can to a great extent be overcome by turning the valve on its side, so the stem will be nearly horizontal. In this position the opening in the valve seat is as low as the bottom of the pipe and permits most of the water to drain out.

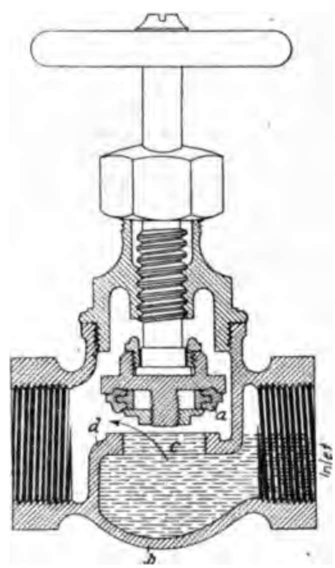


Fig. 85
Globe Valve

ANGLE VALVES.—A type of valve much used for controlling the water supply to separate fixtures is shown in Fig. 86. It is known as an angle valve and is a modification of the globe valve. The openings to an angle valve are at right angles to each other so that the valve can serve the dual purpose of controlling the water and changing the direction of the pipe. Angle valves are made with metal seats and with seats of soft materials, the latter being the better kind for use on water supplies.

LIET CHECK VALVES.—A check valve is an automatic valve that opens to the pressure of water on one side but closes tightly when pressure is applied to the opposite end

of the valve. Where it is necessary that water should always flow in one direction and there is a possibility of a reverse flow, a check valve should be used. There are two common types of check valves; lift check valves, and swing check valves. A lift valve is shown in section in Fig. 87. In this type of valve the check, *a*, seats by gravity when pressure in the system on both sides of the valve is equal. When pressure on the inlet end of the valve exceeds that in the outlet, as, for instance, when a faucet is opened, the pressure unseats the check, *a*, from the seat, *b*, and permits water to flow through the valve. If, on the contrary, there is an excess of pressure on the outlet end of the valve, the pressure will the more tightly seat the check and prevent any water from passing back through it. Check valves are made both for vertical and for horizontal pipes.

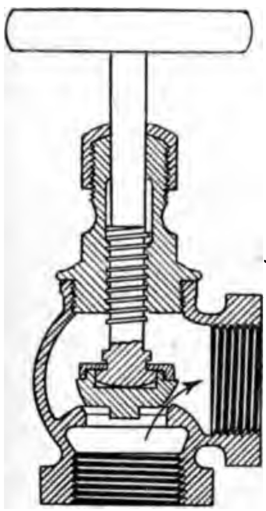


Fig. 86
Angle Valve

SWING CHECK VALVE.—A valve of this type is shown in section in Fig. 88. It derives its name from the fact that the metal flap, *a*, yielding to the pressure of water, swings on the pivot, *b*, and thus presents a straightway opening for the flow of water. This type of check valve compares with the lift check valve about as a gate valve compares with a globe valve. The swing check valve offers less resistance to the flow of water through it and has a straightway opening of almost the full size of the valve. In the lift check

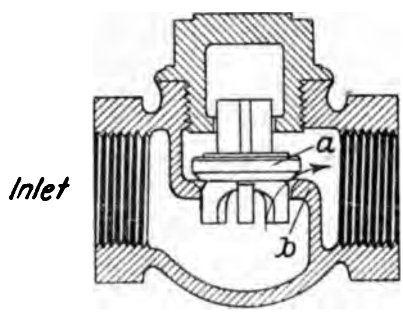


Fig. 87
Lift Check Valve

valve, on the contrary, the water must pass through a reduced opening in the valve seat and must make two right angle turns while doing so.

GROUND KEY COCKS.—Ground key work may be either stop cocks for controlling water in a pipe, or faucets for drawing water at a fixture. The only difference is in their exterior appearance, the principles of construction and operation being the same for both patterns. Ground key cocks can be had for lead pipe, for iron pipe, and, in the case of stop cocks, they may be had with one end threaded for iron pipe and the other end prepared for lead pipe. Cocks for iron pipe can be had tapped with female threads or threaded to screw in a fitting.

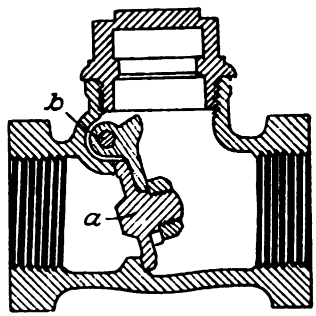


Fig. 88
Swing Check Valve

A sectional illustration of a ground key cock is shown in Fig. 89. The plug, *a*, is ground to a water-tight fit in the cock, *b*, and water is turned on and off by giving a one-quarter turn to the lever, *c*. The principal objection to this kind of a cock is that the constant wearing of the plug and cock every time the water is turned on or off, soon causes the cock to leak, and the leak can only be repaired by regrinding the plug, which is a tedious and rather expensive undertaking, sometimes costing more than would a new cock. Another objection that should not be overlooked, is the quickness with which this type of cock shuts off the water, Where the water pressure is

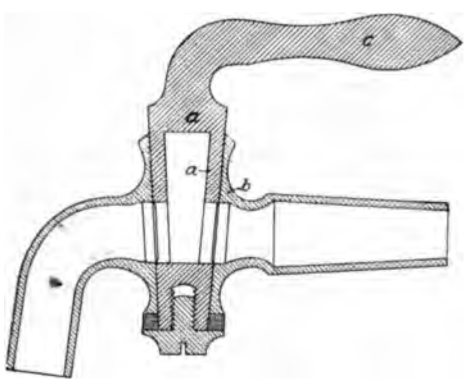


Fig. 89
Ground Key Cock

high, this might cause serious damage to pipes and fixtures.

COMPRESSION COCKS.—A compression cock such as is used at kitchen sinks is shown in section in Fig. 90. In construction it is quite similar to a globe valve and, like one, it closes against the pressure. The core, *a*, of a compression cock is fitted with a soft disk packing, *b*, which can be easily renewed when the cock leaks. They are also fitted with a rubber packing, *c*, or in some cases with a ground joint to prevent water spouting out around the compression stem. Compression stop cocks should be fitted with an auxiliary stuffing box around the stem to withstand the back pressure they are subjected to.

FULLER PATTERN FAUCETS.—A very good type of faucet for low pressure work is shown in section in Fig. 91. This type of cock is quick closing and closes with the pressure, a rubber packing, *a*, effecting the seal. On account of the quickness with which this kind of cock can be closed, each supply pipe to which they are connected should be provided with an air chamber and they should not be used on high pressure work.

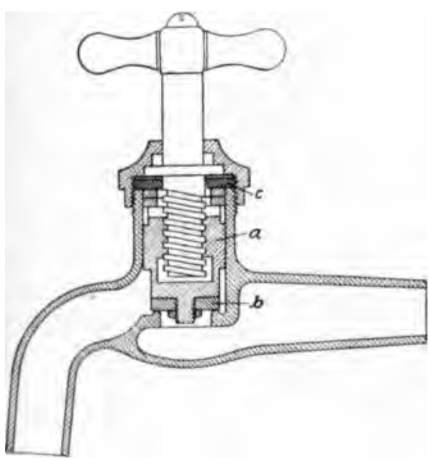


Fig. 90
Compression Cock

SELF-CLOSING FAUCETS.—In institutions like insane asylums, where through carelessness in those who use the fixtures much water will be wasted, it is customary to fit all fixtures with self-closing faucets. Water can be drawn from a self-closing bibb only while it is held open; the moment the hand is removed, the faucet is immediately closed by a spring provided for that purpose. A self-closing sink faucet is shown in Fig. 92. When the stem, *a*, is turned to

the left it raises the block, *b*, thus compressing the spring, *c*, which, as soon as the pressure is removed, returns to its original shape, thus closing the faucet.

The practice has become all too common of installing self-closing faucets in hotels. This practice is bad, however, and should not be continued. Careful measurement has revealed the fact that less water is used when washing in running water from the faucet than when first filling the bowl. But even if more water were used, sanitary consideration and a regard for the wishes of guests would demand faucets that can be regulated. Particular people do not care to wash in a public basin in which there is evidence at times of having been used as a urinal, or has been used possibly by someone suffering from loathsome and contageous diseases; and even though the consumption of water were greater, the hotel rates are sufficient to pay for the extra water consumed.

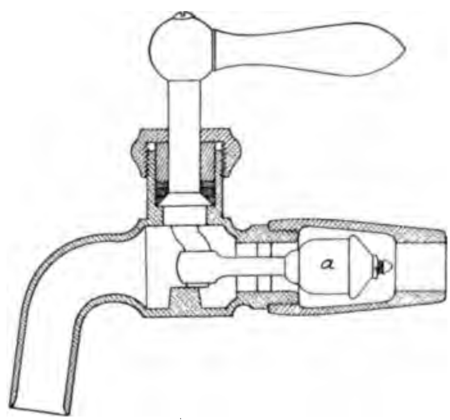


Fig. 91
Fuller Cock

PRESSURE REGULATORS.—Pressure regulators are apparatus for controlling or decreasing the pressure of water within a building and thus relieving the system of excessive stress. By their use, the static pressure within a building can be maintained at a pressure of 15, 25 or more pounds, while the static pressure in the street might exceed 100 pounds; at the same time, the volume of water or the pressure of the water while running will not be affected by the pressure reducing valve. The principle of operation of a pressure regulator can be explained by a reference to Fig. 93. The area of the valve seat, *a*, bears a certain ratio (say one-fourth) to the area of the disk, *b;* consequently, with

a pressure of 100 pounds per square inch in the service pipe, *c*, the valve, *a*, will seat when the pressure in *d* exceeds 25 pounds. This is owing to the greater area in *b*, which compensates for the greater pressure acting on the small area of *a*. That is, 26 pounds pressure per square inch acting on four square inches of disk will equal 104 pounds pressure, enough to close the valve against 100 pounds pressure only on a 1-inch surface. The pressure in *d* at which the valve seats, or in other words, the amount of pressure to be carried in the water supply system, can be regulated by adjusting the fulcrum, *e*. Moving it to the right will increase and moving it to the left will decrease the pressure in the system.

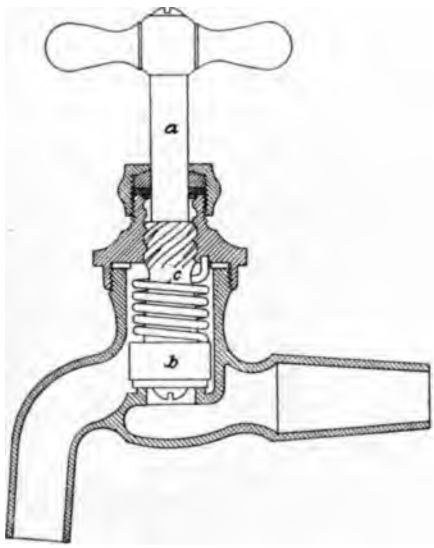


Fig. 92
Self-Closing Cock

A sectional illustration of a pressure regulator extensively used in practice is shown in Fig. 94. In this regulator two pistons, called cups, of different areas are used instead of the two distance valves in the former illustration. The operation of the valve is as follows: When water is admitted to the pressure side of the regulator, it passes

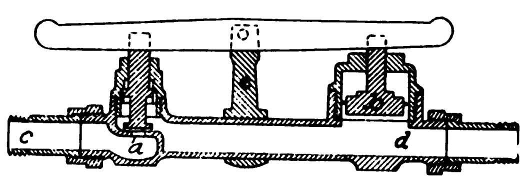


Fig. 93
Pressure Regulator

through the valve port and fills the system of piping on the house side; as soon as the system of piping is filled, the back pressure acts on the upper cup and tends to raise the stem and thus close the valve. As the area of the upper cup is greater than that of the lower cup, a less pressure per square inch is required on the low-pressure side to exceed the pressure exerted on the lower cup on the high-pressure side; consequently, when the pressure on the house side exceeds a certain percentage of the street pressure, the valve will close. As soon as a faucet on the house side of the regulator is opened, it lowers the pressure on that side, and the high-pressure acting on the lower cup will again open the valve.

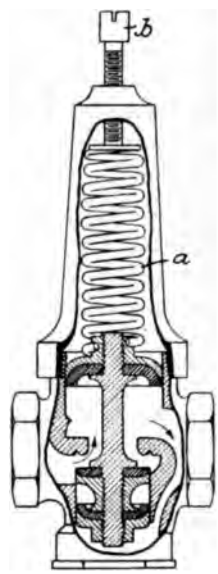


Fig. 94
Pressure Reducing Valve

The area of the low-pressure cup bears a certain ratio to that of the high-pressure cup, consequently, if provision were not made to overcome the difference between the force tending to close the valve and the force tending to hold it open when the pressure on both sides is equal, it would be impossible to maintain a pressure on the house side of the valve greater than that due to the ratio between the two cups. For instance, if the ratio of area of the high-pressure cup to that of the low-pressure cup were one to four and the pressure on the street side were 100 pounds per square inch, the valve would close when the pressure on the house side exceeded 25 pounds per square inch and no higher pressure could be maintained. To overcome this difficulty a spring, *a*, and tension screw, *b*, are provided. Turning the screw to the right increases the tension of the spring against which the low pressure must act to close the valve, and, in proportion as the tension screw is screwed down, the pressure on the house side of the valve will be increased.

There is a limit to the reduction of pressure possible to

obtain by means of a pressure regulator. This reduction depends to a great extent on the pressure of water on the street side of the valve. For instance, the lowest pressure it is possible to obtain for 40 prounds pressure is about 14 pounds; 50 pounds pressure, 16 pounds; 60 pounds pressure, 18 pounds; 70 pounds pressure, 20 pounds; 85 pounds pressure, 21½ pounds; 100 pounds pressure, 23 pounds; 115 pounds pressure, 25 pounds; 125 pounds pressure, 27 pounds; 135 pounds pressure, 29 pounds; 150 pounds pressure, 31 pounds; 175 pounds pressure, 35 pounds; 200 pounds pressure, 39 pounds.

On account of the weight of the stem and the friction of the moving parts, it is impossible to obtain so low a reduction as zero, but any pressure between the two extremes mentioned can be secured by adjusting the tension screw on top of the cap.

A relief or safety valve should always be used in connection with a pressure regulator, to provide relief for the system should excessive pressure be generated by the water heating apparatus.

CHAPTER XX
DETAILS OF WATER SUPPLY

SERVICE CONNECTIONS.—Small service pipe connections to street mains are usually made by drilling and then tapping with a pipe thread the street main. A brass corporation cock, *a*, Fig. 95, to which is connected the service pipe, *b*, is then screwed into the street main. When the service pipe is made of brass or wrought iron, a short length of lead pipe laid wavy, should be inserted to provide a flexible connection that will not be affected by a subsequent settlement of either the service pipe or the street main.

In some waterworks systems where the pressure is low the street main is drilled and a corporation cock driven instead of being screwed into the main. While this form of corporation cock is extensively used, it is not wholly satisfactory even for low pressure systems, and owing to the great liability of their leaking they should never be used where the street mains are subjected to high pressure.

Connections to the water mains are made by an employee of the municipality or water company that owns the system. This is done while the mains are under pressure and is accomplished without the loss of water from the mains. It is made possible by the use of a drilling and tapping machine designed for the purpose.

The largest tap permitted by most water companies is 2 inches in diameter; hence, when larger sizes of service pipes are required, connections for them must be made to the street main either by inserting a special fitting, which is by far the better practice, or by means of a multiple service connection, as shown in Fig. 96. With a moderate sized street main, connections for service pipes over 2½ inches diameter should be made by means of a special fitting; for all smaller sizes of service pipes and for all sizes of service pipes when the water main is extremely large, connections may be made by means of a multiple connection. In calculating the number of branch services for a multiple

connection, allowance should be made for the greater amount of friction in small pipes. This is no inconsiderable item, as the following will show: At the same velocity of flow, doubling the diameter of a pipe increases its capacity four times; but the same head or pressure will produce different velocities in pipes of different sizes or lengths, and doubling the diameter of a pipe when the pressure remains constant, increases the capacity of the pipe about six times, the difference being usually stated to vary as the square root of the fifth power of the diameter. The number of small pipes required to equal the capacity of a large one can be found in Table LI of equation of pipes.

In the table, figures above the diagonal line refer to standard wrought pipes the diameters of which vary a little from the actual diameters given. In the lower part of the table the figures refer to pipes of the actual sizes given.

Fig. 95
Connection to Street Main

The table is used in the following manner: If it is desired to know the number of $\frac{3}{4}$-inch taps or pipes that will equal in discharging capacity a 2-inch pipe, glance down the column marked 2 to the intersection of the line in the first column marked $\frac{3}{4}$. This shows that it requires fourteen $\frac{3}{4}$-inch taps or pipes to equal one 2-inch pipe. To find the number of pipes of one size that equals the discharging capacity of another, in the lower part of the table, follow down the columns the size of the smaller pipe until it intersects the line of the larger one. Thus to find the number of 2-inch pipes that equal a 10-inch pipe, follow down the column marked 2 to where it intersects the line marked 10 and it will be found that 80.4 two-inch pipes equal in discharging capacity one 10-inch pipe.

In like manner the size of main required to serve several branches can be determined. Suppose it is necessary to find the diameter of main that will serve one 2-inch, one 3-inch, and one 4-inch pipe. Use the capacity of the small-

TABLE LI. Equation of Pipes

DIAMETERS OF STANDARD STEAM AND GAS PIPES

Dia	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488	3,014	3,786	4,904	5,927	7,321	8,535	9,717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1,096	1,328	1,668	2,161	2,615	3,226	3,761	4,282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1,070	1,263	1,576	1,837	2,092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20,327	7,810	2,691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26,676	10,249	3,532	1,102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42,624	16,376	5,644	1,761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249,351	95,818	33,020	10,301	4,554	2,434	1,465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia

ACTUAL INTERNAL DIAMETERS

est pipe as a measure. Then: One 2-inch pipe has the capacity of one 2-inch pipe; one 3-inch pipe has the capacity of 3.06 2-inch pipes; one 4-inch pipe has the capacity of 6.45 2-inch pipes. The combined capacity of the pipes equals that of 10.53 2-inch pipes. Required, a water main with the capacity of 10.53 2-inch pipes. From the table it is found that a 5-inch pipe has the capacity of 11.9 2-inch pipes, so would be more than large enough to serve all the branches.

Hotels, clubs, hospitals and other buildings that require an uninterrupted supply of water should when possible be provided with two service pipes. Each service pipe should be of sufficient capacity to supply the entire building and should be connected to the street main in different streets. The service pipes should then be cross connected within the building, so that if water is shut off from one city main an adequate supply can be drawn from the other one.

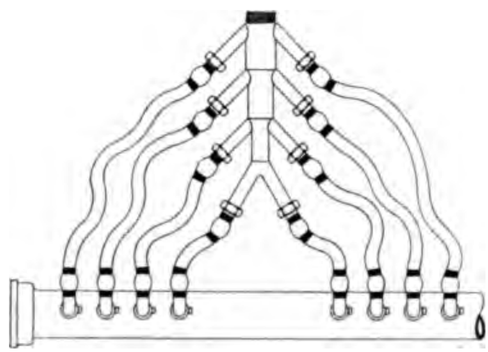


Fig. 96
Multiple Connection to Street Main

Service pipes are usually provided with a stop cock located at the curb. This curb cock gives the water company control of the supply within a building, so that water can be shut off at any time without digging down to the corporation cock or entering the premises.

The comparative capacities of pipes of standard sizes, when the velocity of flow remains constant, or the number of times the area of one pipe is contained in that of a larger, can be found in Table LII.

Suppose, for instance, it is necessary to know how many times the area of a ¾-inch pipe is contained in that of a 2½-inch pipe. Glancing down column 1 to the size marked 2½, then along the horizontal line until it intersects

TABLE LII. Comparative Areas of Pipes

Size of Pipe	1/8	1/4	3/8	1/2	3/4	1	1¼	1½	2	2½	3	3½	4	5	6	7	8	9	10
1/8	1.																		
1/4	1.9	1.																	
3/8	3.3	1.8	1.																
1/2	5.3	2.9	1.5	1.															
3/4	9.3	5.2	2.7	1.7	1														
1	14.7	7.7	4.1	2.6	1.6	1.													
1¼	26.2	14.3	7.8	4.9	2.8	1.6	1.												
1½	35.6	19.5	10.6	6.6	3.8	2.4	1.3	1.											
2	58.6	32.2	17.5	11.0	6.9	3.9	2.2	1.6	1.										
2½	83.6	44.6	25.0	15.7	9.0	5.5	3.2	2.3	1.4	1.									
3	129.1	71.0	38.5	24.2	13.8	8.5	5.0	3.6	2.2	1.5	1.								
3½	172.8	95.0	51.6	32.4	18.5	11.4	6.6	4.8	2.9	2.0	1.3	1.							
4	222.5	122.3	66.4	41.7	23.8	14.7	8.5	6.2	3.8	2.6	1.7	1.3	1.						
5	349.4	192.0	104.3	65.6	37.4	23.1	13.3	9.8	5.9	4.1	2.7	2.0	1.5	1.					
6	505.0	277.5	150.7	94.7	54.1	33.4	19.3	14.1	8.6	6.0	3.9	2.9	2.2	1.4	1.				
7	677.2	372.1	202.2	127.0	71.3	44.9	25.9	19.0	11.5	8.1	5.2	3.9	3.0	1.9	1.3	1.			
8	878.3	480.7	261.2	164.1	93.8	58.0	34.5	24.5	14.9	10.4	6.7	5.0	3.9	2.5	1.7	1.3	1.		
9	1112.4	611.2	332.1	208.7	179.3	73.4	42.7	31.2	19.0	13.3	8.7	6.4	5.0	3.1	2.2	1.6	1.2	1.	
10	1378.3	757.3	411.5	258.6	147.8	91.3	52.7	38.6	23.5	16.5	10.6	7.9	6.2	3.9	2.7	2.0	1.5	1.2	1.

the column headed $\frac{3}{4}$, it will be seen that a $2\frac{1}{2}$-inch pipe is equal in area to nine $\frac{3}{4}$ pipes.

SIZES OF WATER PIPES.—Water supply systems should be so proportioned that a plentiful supply of water at low velocity can be had at all fixtures. If pipes are too small, there will be the annoyance of one faucet robbing another, also, owing to the high velocity of flow when water is being drawn, a disagreeable singing or hissing noise will be heard in the pipes and the sound will be conveyed to all parts of the building where there are pipes.

In proportioning a water supply system the chief condition to be ascertained is the probable number of fixtures at which water will simultaneously be drawn. In residences and other buildings with comparatively few fixtures the supply pipes should be proportioned to supply all the fixtures simultaneously. In hotels, apartment houses and like buildings, however, such provision is unnecessary. It is not probable that more than one fixture at a time will be in use in a bath room, nor is it probable that more than one fixture at a time will be used in the kitchen, although it is quite probable that fixtures in kitchen and bath room will be simultaneously used; hence, if provision be made to supply at the same time one fixture in each group within a building, the pipes will be of sufficient capacity to meet all requirements.

The largest pipe used to supply any fixture is $\frac{3}{4}$-inch diameter and the average size $\frac{1}{2}$-inch in diameter. Faucets and cocks for $\frac{3}{4}$-inch pipes seldom have an unobstructed waterway larger than $\frac{1}{2}$-inch diameter, while the waterway of $\frac{1}{2}$-inch cocks and faucets seldom exceeds $\frac{3}{8}$ inch in diameter; hence, if in all water pipes an allowance is made of the capacity of a $\frac{1}{2}$-inch pipe for one fixture in each group, the system will be so proportioned that an adequate supply of water at low velocity will be had at all fixtures. An exception to the foregoing statements must be made in the case of public toilet rooms and batteries of wash basins in factories or other institutions. All the fixtures in such batteries might be used at the same time and an allowance

of the capacity of a ½-inch pipe for each fixture should be made.

EXAMPLE—What size of water main will be required for an apartment house of fifteen families, each family being provided with bath room and kitchen?

SOLUTION—Fifteen bath rooms and fifteen kitchens equal thirty groups of fixtures to be supplied at once, and allowing the capacity of a ½-inch pipe for each group of fixtures requires a pipe with a capacity of thirty ½-inch pipes. From Table LI will be found that a 2-inch standard pipe has the required capacity.

EXAMPLE II—What size of service pipe will be required to supply a hotel equipped with 280 bath rooms and 20 other groups of fixtures?

SOLUTION—$280 + 20 = 300$, and according to Table LI about a 4½-inch pipe would equal in capacity three hundred ½-inch pipes.

WATER REQUIRED FOR VARIOUS PURPOSES.—The following information will be found helpful when determining the daily consumption of water for a building:

In estimating the demand for swimming pools, it is usually figured to fill pool in 24 hours and to refilter all water in pool once every 24 hours. A pool for 100 persons has a capacity of about 50,000 gallons.

For sprinkling 100 square feet of lawn, about 1 cubic foot, or 7 to 8 gallons. For soaking 100 square feet of lawn, about 2½ cubic feet, or from 15 to 16 gallons. To flush closet each time, 5 to 6 gallons. The actual rate of discharge from water closets is about 1¼ gallons per second. To fill the lavatory ordinary, about 1½ gallons. To fill bath tub ordinary, about 20 gallons.

The consumption of water by farm animals varies greatly, depending upon the season of the year, the age and the individual habits of the animal, and local conditions. The following table will give a good idea, however: Horse, 5 to 10 gallons per day; cattle, 7 to 12 gallons per day; hogs, 1½ to 2½ gallons per days; sheep, 1 to 2 gallons per day.

For mixing concrete 40 pounds of water are required for each 100 pounds of cement. Forty pounds of water equals 4.82 gallons.

The amount of water required for boiler feeding can be found in Table LIII.

TABLE LIII. Water Required per Minute to Feed Boilers

(Using the "Centennial Standard"—30 pounds or 3.6 gallons of water per horse power per hour, evaporated from 100° F. to 70 pounds steam pressure per square inch.)

H. P. Boiler	Feed Water Gallons	H. P. Boiler	Feed Water Gallons	H. P. Boiler	Feed Water Gallons	H. P. Boiler	Feed Water Gallons	H. P. Boiler	Feed Water Gallons
20	1.2	60	3.6	110	6.6	190	11.4	400	24.0
25	1.5	65	3.9	120	7.2	200	12.0	450	27.0
30	1.8	70	4.2	130	7.8	225	13.5	500	30.0
35	2.1	75	4.5	140	8.4	250	15.0	600	36.0
40	2.4	80	4.8	150	9.0	275	16.5	700	42.0
45	2.7	85	5.1	160	9.6	300	18.0	800	48.0
50	3.0	90	5.4	170	10.2	325	19.5	900	54.0
55	3.3	100	6.0	180	10.8	350	21.0	1000	60.0

Forty to 60 pounds of condensing water are required for each pound of steam condensed to moderate temperature. Sixty to 100 pounds of water per pound of steam when the water used is at the higher temperature common to cooling tower practice. Consumption of water in military camp is about 10 gallons per capita daily.

TABLE LIV. Flow of Water at Plumbing Fixtures*

Kind of Fixtures	Fair Flow Gallons Per Minute	Good Flow Gallons Per Minute	Excellent Flow Gallons Per Minute
Kitchen Sink Bibb	2	4	6
Pantry Sink, High Goose Neck Cocks	2	2	3
Pantry Sink, Large Plain Bibbs	4	6	8
Vegetable Sink Bibbs	2	4	6
Laundry Tray Bibbs	4	6	8
Slop Sink Bibbs	3	4	6
Basin Cocks	2	3	4
Bath Cock, (either hot or cold)	3	4	6
Shampoo Spray	½	1	2
Liver Spray	1	2	3
Shower Baths, 5-inch Rain Heads	2	3	4
Shower Baths, 6½-inch Rain Heads	2	3	5
Shower Baths, 8-inch Rain Heads	4	6	8
8-inch Tubular Shower Heads	6	8	10
Needle Baths	20	30	40
Manicure Tables	1	1½	2

*Speakman.

Water flows from an ordinary kitchen faucet at the rate of about 3 gallons per minute in average use. The range of flow at fixtures of different kinds under a pressure of 30 pounds per square inch can be found in Table LIV.

CHAPTER XXI
PUMPS AND PUMPING

Lift or Suction Pumps

PRINCIPLES OF OPERATION.—The operation of a suction pump is dependent on and its efficiency limited by atmospheric pressure. If there were no atmospheric pressure there could be no suction lift to a pump. This is shown by a reference to the suction pump, Fig. 97, which consists of a piston, *a*, in a pump barrel or cylinder, *b*, a valve, *c*, that opens on the down stroke of the piston and closes on the up stroke, and a valve, *d*, that opens on the up stroke of the piston and closes on the down stroke. The operation of the pump is as follows: When the piston, *a*, makes an up stroke it exhausts some air from the suction pipe, *e*, and a sufficient quantity of water flows in to replace the exhausted air and balance the atmospheric pressure on the water outside. On the down stroke of the piston the exhausted air which has been confined in the pump cylinder escapes through the valve, *c*, which opens on the down stroke. The next up stroke of the piston still further exhausts air from the suction pipe and a still higher column of water flows in to replace the exhausted air. Repeated strokes of the piston exhaust all air from the suction pipe and pump cylinder, which then fill with water which is pumped out as was the air.

LIFT OF A PUMP.—Theoretically a pump will raise water a distance equal to the height that atmospheric pressure will balance a column of water in a perfect vacuum. Experience and experiment, however, have demonstrated that a pump will raise water only about .75 of the theoretical height. This difference between the theoretical and the actual lift of a pump is due to the loss of head caused by friction in the pipe, and the impossibility of securing a perfect vacuum on account of mechanical imperfections in the pump and connections, air in the water and vaporization of the water itself. The constant .75 holds true, however, only

for water at ordinary temperatures. Any appreciable raise in the temperature of water will cause a corresponding loss of lift. This is due to the fact that in a vacuum water vaporizes at a lower temperature than when under pressure, and when air is exhausted from the suction pipe of a pump connected with a hot water tank or receiver, the water instantly flashes into vapor and fills the suction pipe, preventing the formation of a vacuum. Water of temperatures higher than 180 degrees Fahrenheit cannot successfully be raised by suction but for the best operation must flow into a pump by gravity. Waters of lower temperatures but over 100 degrees Fahrenheit are much easier handled when they flow by gravity into the pump cylinder.

Fig. 97
Suction Pump

Atmospheric pressure varies with the elevation, that is, the distance above or the depth below sea level; hence on the side or top of a mountain the atmospheric pressure and consequently the lift of a pump will be less than at the sea level. Also, the atmospheric pressure and lift of a pump in a deep pit or mine will be greater than at sea level. The atmospheric pressure at sea level varies with the conditions of weather, but for practical purposes is taken as 14.7 pounds per square inch, and as 1 pound pressure will balance a column of water 2.309 feet high, it follows that in a perfect vacuum atmospheric pressure should balance a column of water $14.7 \times 2.309 = 33.95$ feet high. Atmospheric pressure at different altitudes with equivalent head of water and the vertical suction lift of pumps can be found in Table LV.

In addition to the vertical lift, a suction pump will draw water horizontally a great distance; nevertheless, when water must be conveyed any great distance, better

results are obtained by using a *force pump* and placing it close to the source of supply.

FORCE PUMPS.—Suction pumps are limited in the height to which they can deliver water by the atmospheric pressure at the elevation where they are installed; furthermore, they cannot be used to circulate water through a closed circuit. Hence, when water must be elevated a considerable distance through closed pipes, as, for instance, in filling a house tank, a force pump must be used.

TABLE LV. Safe Suction Lifts of Pumps

Elevation Above Sea Level Feet	Atmospheric Pressure Pounds Per Square Inch	Barometric Pressure Inches Mercury	Temperature of Water Raised Degrees Fahrenheit				
			60	90	120	150	180
			Safe Suction Head for Pump (Feet)				
10,000	10.107	20.582	17.0	16.4	14.7	11.3	4.7
5,000	12.224	24.890	20.5	19.9	18.2	14.8	8.2
4,000	12.689	25.837	21.5	20.9	19.2	15.8	9.2
3,000	13.169	26.813	22.4	21.8	20.2	16.8	10.2
2,000	13.665	27.824	23.2	22.6	21.0	17.6	11.0
1,000	14.174	28.861	24.1	23.5	21.9	18.5	11.9
Sea level	14.696	29.925	25.0	24.4	22.8	19.4	12.8
Tension of water vapor at Various temperatures		Lbs. per Sq. In.	.255	.693	1.683	3.706	7.500
		Inches mercury	.518	1.410	3.427	7.547	15.272

A simple hand force pump is shown in Fig. 98. It combines the functions of a lift pump with that of a force pump. Water is raised to the cylinder by suction as in a lift pump, but when the solid piston, *a*, descends, the confined water cannot escape to the top of the piston, as in the case of a suction pump, but is forced out through the valve, *b*, to the house tank or other place of storage. This pump is known as a single stroke pump, as it lifts and forces with each alternate stroke of the piston.

SLIP.—At the end of the up stroke of the piston, the moment when it begins a down stroke, there is a brief interval of time during which both valves *b* and *c* are open,

and during that time water flows back to the source of supply. This back flow of water is known as the *slip* of a pump. It increases with the height of the lift of the suction, the height to which the water is forced and the slowness of the valves in seating. When the vertical lift of a pump is small but the suction is long and the pump forces against a low head, the momentum of the moving column of water sometimes carries it forward while both valves are open; such a flow is known as the *negative slip* of a pump. The slip of a pump is a limiting factor in its capacity; when the slip is great the capacity of a pump will be correspondingly decreased, and when the negative slip is great the capacity of the pump will be greatly increased over its theoretical capacity.

AIR CHAMBERS.—When a force pump is operated it alternately sets in motion and brings to rest the entire moving column of water. As water is practically incompressible, the sudden starting and stopping of the column will cause water hammer that is both annoying to occupants of a house as well as damaging to the pump and pipes. This water hammer can be practically overcome by using an air chamber on the discharge pipe and so locating the air chamber that it will remain full of air and receive the initial impulse of the water. An air chamber not only prevents water hammer, but also equalizes the flow between strokes of the piston. When pumps are operating under high pressures the air is soon absorbed from the air chambers, which are thus rendered useless unless some means are provided for re-

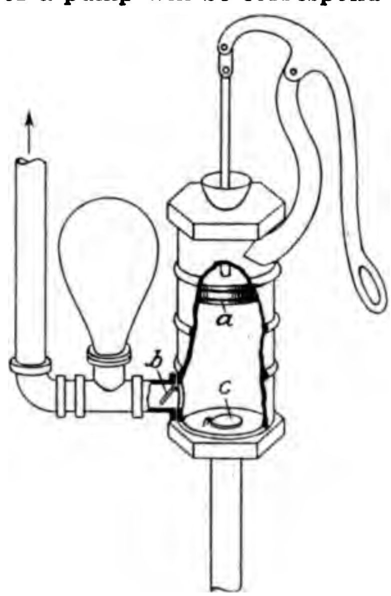


Fig. 98
Force Pump

charging them. A simple contrivance for charging air chambers of steam pumps is shown in Fig. 99. The air chamber and water cylinder of a pump are connected together through a gate valve, *a*, pipe, *b*, and a check valve, *c*, which opens towards the air chamber. Another check valve, *d*, that opens towards the pump is screwed to the pipe as shown. The standpipe, *b*, stands partly full of water. Then with the valve, *a*, properly throttled, when the water piston, *e*, makes a stroke to the left, some of the water will be drawn into the cylinder, and air will enter check valve, *d*, to take its place. On the reverse stroke of the piston, water is forced into the pipe, *b*, and as the confined air cannot escape through the check valve, *d*, it is forced into the air chamber, thus keeping it charged.

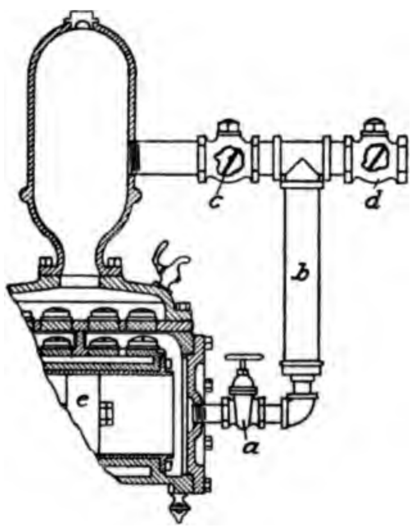


Fig. 99
Air Chamber on Pump

SINGLE DIRECT-ACTING STEAM PUMPS.—The type of steam pump most commonly used for house pumps is a single direct-acting pump shown in Fig. 100. The operation of the pump is as follows: Steam enters the cylinder, *a*, from the steam chest, *b*, through the port, *c*, and pushes the piston, *d*, to the left, the steam exhausting from the left side of the piston through the port, *e*, and exhaust, *f*, to the atmosphere. When the piston has almost reached the end of its stroke, the arm, *g*, link, *h*, and rod, *i*, reverse the auxiliary piston, *j*, and slide valve, *k*, so that steam is now admitted to the left side of the piston through port, *e*, and as the piston travels to the right the exhause steam escapes through port, *c*, and exhaust, *f*, to the atmosphere. The

reciprocating motion of the steam piston is transmitted to the pump piston, *l*, in the water end of the pump by means of the piston rod, *m*, to which it is direct connected. Then, as the pump piston travels to the left, water flows through the suction valve, *n*, into the pump cylinder, while the water to the left side of the piston is forced through the valve, *o*, into the discharge pipe. On the reverse stroke of the piston, water flows through the suction valve, *p*, into the pump cylinder, while water on the right side of the piston is forced out through discharge valve, *q*, into *the discharge* pipe. An air chamber, *r*, on top of the valve chamber reduces shock from water hammer and promotes steady flow. Two drip cocks, *s s*, serve to drain water of condensation

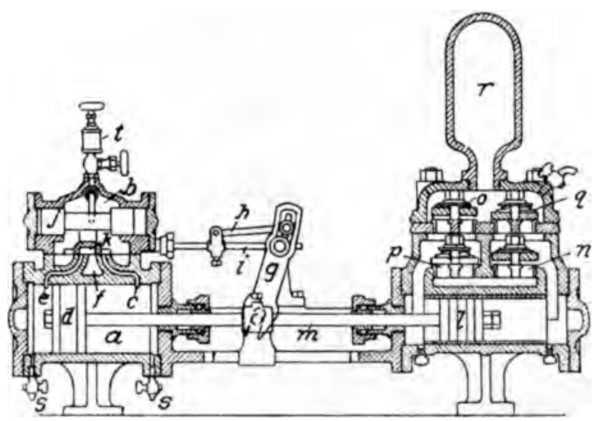


Fig. 100
Steam Pump

from the steam cylinder and a lubricator, *t*, oils the working parts in the steam chest. This pump is known as a double stroke pump, as it both lifts and forces with each stroke of the piston. For low pressure service the piston in the water end of a pump may be packed with a fibrous packing; for high pressure service, however, the packing should be of metal.

HORSEPOWER OF PUMPS.—The horsepower necessary to elevate water to a given height can be found by multiplying the weight of water in pounds elevated per minute by the height in feet, and dividing the product by 33,000. An

allowance or deduction of 25% from the theoretical horsepower should be made to allow for the loss due to friction, when the runs are not long. If the discharge pipe is long, or contains many bends and branches, the frictional resistance of the pipe and fittings should be calculated.

CAPACITY OF PUMPS.—The diameter of cylinder for a single-acting pump required to deliver a certain quantity of water per minute can be found by the formula:

$d = \sqrt{\frac{g}{.034\,l\,n}}$, in which l = length of stroke in feet, g = number of gallons to be delivered per minute, n = number of strokes per minute, d = diameter of pump in inches.

EXAMPLE—What diameter of pump plunger will be required to discharge 114 gallons of water per minute; speed of pump, 90 strokes; length of stroke, 1 foot?

SOLUTION—Substituting values given in the example,

$$d = \sqrt{\frac{114}{.034 \times 1 \times 90}} = 6.1 \text{ inch diameter.—Ans.}$$

When the diameter of a cylinder and the length of piston travel per minute are known, the quantity of water a pump will discharge can be found by the formula:

$q = l\,a\,s$, in which q = cubic feet of water delivered per minute, l = length of stroke in feet, a = area of piston or plunger in feet, s = number of strokes per minute.

EXAMPLE—What will be the discharge in cubic feet per minute from a single direct-acting pump with water piston 6 inches in diameter and length of stroke 8 inches, when running at a speed of 30 strokes per minute?

SOLUTION—The area of a 6-inch piston is .2 square foot. An 8-inch piston stroke equals .666 foot. Then,

$$.666 \times 30 \times .2 = 3.99 \text{ cubic feet of water per minute.—Ans.}$$

ACTUAL PERFORMANCE OF HOUSE PUMP.—The Union Central Office Building, Cincinnati, Ohio, is 30 stories tall. To pump water to the house tanks located on the 18th and 30th floors, there are two Fairbanks-Morse house pumps, size 12 x 7 x12 and 18 x 7 x 12 inches. Only one is in service at a time, the other being kept in reserve, and the two are used on alternate days. An average of 680 cubic feet of water was pumped from the engine room service tank per hour to the tank on the 30th floor, which is about 434 feet above the floor of the engine room.

The steam required per hour to pump the water was 461 pounds, or 1.47 cubic feet of water pumped with 1 pound of steam. The eight-hour test indicated that $0.477 in fuel was consumed to maintain and operate the house pump. To pump 1000 gallons of water took 90.7 pounds of steam, and 9.96 pounds of coal, making the cost of coal $0.010906.

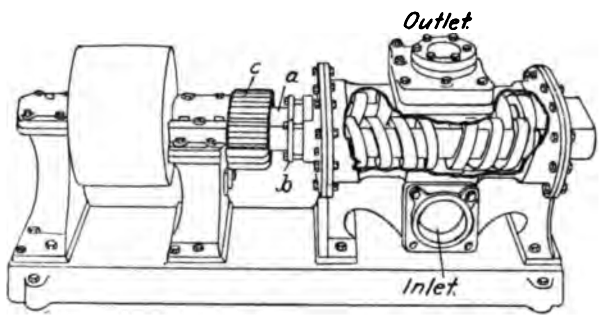


Fig. 101
Screw Pump

QUIMBY SCREW PUMP.—Electrically driven centrifugal or rotary pumps are extensively used in connection with domestic water supplies to raise water to the house tank. One type of electrically driven pump is the Quimby Screw Pump, shown in Fig. 101. This type of pump is suited principally to forcing water and not to raise it by suction; hence to operate successfully it should be set at such a level that water will flow into it by gravity. When water does not flow to the pump by gravity, the suction pipe should be made short and straight as possible, and should be provided with a foot valve. The four screws that act as pistons in propelling the water are mounted in pairs on parallel shafts and are so arranged that in each pair the thread of one screw projects to the bottom of the space between the threads of the opposite screws. The pump cylinder fits the perimeters of the threads closely without actual contact, and the faces of the intermeshing threads make a close running fit without bearing on and wearing the face of the screws. There is no end thrust on the screws in their bear-

ings, because the back pressure of the column of liquid is delivered to the middle of the cylinder and the endwise pressure upon the screws in one direction is exactly counterbalanced by a like pressure in the opposite direction. The suction opens into a chamber underneath the pump cylinder and the liquid passes through this chamber to the two ends of the cylinder, and is forced from the two ends towards the center by the action of the two intermeshing pair of threads, and thence out through the discharge port to the house tank. The power to drive the pump is applied to the main shaft, *a*, and part of it is transmitted to the auxiliary shaft, *b*, by the gears, *c*.

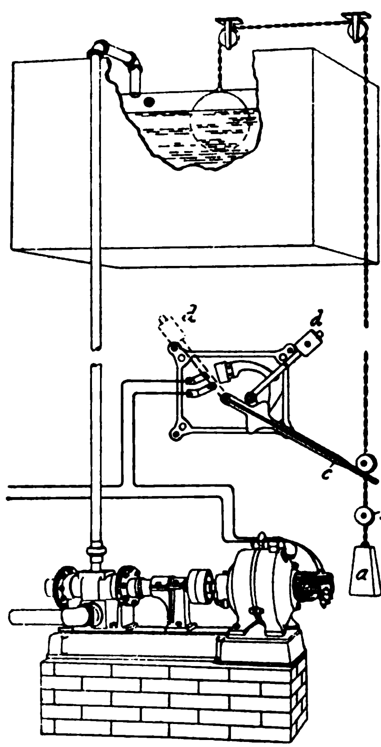


Fig. 102
Automatic Starter for Pump

Pumps for house service are usually fitted up to work automatically. The manner of so connecting a Quimby Pump is shown in Fig. 102. The pump is operated by a direct connected electric motor that is controlled by a weighted float in the house tank. When water in the tank is low, the weighted float raises the chain and counterweight, *a*, until the disk, *b*, trips the switch lever, *c*, throwing the contact bar, *d*, over, as shown by dotted lines, to close the circuit and turn the electric current on to the motor. Then, as the tank fills with water, the float raises and the counterweight pulls down on the chain until the upper disk trips the lever, *c*, thus breaking the circuit and shutting off current from the motor. By adjusting the two disks the

pump can be made to operate under the slightest loss of head in the tank, but it is better to so place the disks that they will close the switch when the tank is almost empty and open it when the tank is full. This avoids frequently starting and stopping the pump and insures a frequent change of water in the tank.

Screw pumps run at speeds ranging from 900 to 1,400 revolutions per minute, according to their size and the service under which they operate. Direct current 110, 220 or 500-volt motors of General Electric, Crocker-Wheeler or Sprague types, are found satisfactory for this work.

Electrically driven pumps of the plunger type are sometimes used for house service pumps. Pumps of this type, however, should be provided with a rheostat or starting box to turn the current on to the motor gradually. If the full current were turned on instantly the armature would probably be burned out; also the pounding due to suddenly starting in motion a large column of water might injure some of the more delicate working parts of the pump.

Motors for pumps operating under a variable load should be compound wound. Those operating under a constant load, should be shunt wound. A series-wound motor when the load is removed is liable to run away or wild.

Slow operating pumps that are direct connected should have slow speed motors. For high speed pumps, also for gear connected pumps, high speed motors may be used.

HOT AIR PUMPING ENGINES.—Hot Air Pumping Engines are used for supplying water to country or suburban residences, and in tall apartment houses to pump water from the service pipe to the house tank on the roof. This type of pump can be operated by any kind of fuel and requires no skilled help to run it. In suburban localities, where a hydraulic ram or a windmill would not be practicable, a hot air pumping engine will prove the next least expensive to operate.

SUCTION TANKS.—If large steam pumps, such as are used for fire pumps and large electric pumps such as are used to fill house tanks on tall buildings, were allowed to pump water direct from the city mains, they would cause

considerable annoyance while operating by reducing the pressure and thus decreasing the flow of water in other supply systems in the neighborhood. Furthermore, the operation of the pump might cause water ram in the mains that would be annoying to other water consumers and damaging to the water supply system. For these reasons, also to store a supply of water on the premises to provide against shortage should water be temporarily shut off from the street mains, suction tanks should be provided in all large buildings.

Suctions tanks usually consist of an open steel tank covered with steel or wooden planking. Sometimes, however, they are enclosed rectangular steel tanks with a manhole and hinged cover, through which access may be had to the interior of the tank.

The supply pipe to suction tanks is generally so large that an ordinary ball cock of the full calibre of the pipe would be subjected to too severe a strain, hence large sizes of supply pipes are usually provided with a Ford balanced ball cock. Suction pipes from suction tanks to house pumps are usually cross-connected to the street supply, so in case of emergency, as for instance during a fire, water can be pumped direct from the city mains. Suction tanks should have sufficient capacity to store at least one day's supply of water for the entire building; when space permits, it is better to provide capacity for two days' storage. This quantity will tide over any probable period of time that water will be shut off from the street mains.

HOUSE TANKS.—House tanks are used to store water for the supply of buildings and should be located at least ten feet above the level of the highest fixture to be supplied. There are two kinds of tanks commonly used, wooden and iron tanks. When located outside of buildings on roofs or in other exposed positions, wooden tanks are generally used; when located inside of buildings, iron tanks are generally used. During warm weather moisture condenses on the outside of iron tanks, and if not cared for will drip to the floor and wet both floor and ceiling below. To prevent this a drip pan should be placed under all iron tanks and a drip

pipe from the pan extended to some convenient sink or connected to the overflow pipe from the tank.

Lead-lined wooden tanks were formerly extensively used, and in some localities are still, to a limited extent, but owing to the liability of carbonates or sulphates of lead being dissolved from the lining and poisoning the water, lead should not be used for tank linings, particularly in localities where the water is soft.

Copper-lined wooden tanks are sometimes used. From a chemical standpoint, copper linings are not so objectionable as lead, particularly when the copper is tinned; however, copper linings present so many joints and seams that some of them are liable to leak, and, in some waters, soldered copper joints rapidly disintegrate, owing either to a chemical or galvanic action of the metals.

In extremely tall buildings, fixtures on the lower floors are supplied with water direct from the street mains; the upper floors are supplied with water from the house tank on the roof, and intermediate tanks are installed, so that not more than eight floors of the building are supplied with water from any one tank. In such installations the house supply from the roof tank should be cross-connected to the house supply from all the intermediate tanks and to the house supply for the lower floors, so that in case of necessity the entire building can be supplied with water from the house tank, which can be filled by pumping from the suction tank.

Storage tanks should be provided with overflow pipes of sufficient capacity to safely carry off the greatest quantity of water likely to be discharged by the supply pipe. It is a safe rule to allow for the overflow pipe twice the diameter or four times the sectional area of the supply pipe. Overflow pipes from tanks located on roofs of buildings may discharge onto the roof. Overflow pipes from tanks located inside of buildings should discharge into a properly trapped and water-supplied sink or a sump in the basement. Under no circumstances should they be connected direct to the drainage system.

The size of storage tanks depends upon the number of

people to be supplied, and the length of time they are to supply water without being replenished. They should have sufficient storage capacity for at least one day's supply, to tide over possible periods of breakdown of pump or boiler. When figuring the capacity of storage tanks, 100 gallons of water per day per capita should be allowed in hotels, hospitals, apartment houses and public institutions.

In large office buildings many stories in height, also large hotel buildings, the tanks must be sufficiently large to supply water for the greatest period of time the water is likely to be shut off from the mains. In large important buildings of such character, it is advisable to have as many as three, and four if possible, separate service pipes connected to mains in the different streets. This is quite possible when the building fronts on three or four streets, and it might be accepted as a rule to run a service pipe from the water main in every street on which a building fronts. It is not likely that water will be shut off from all the streets at one time, and the possibility of interrupted service becomes less the greater the number of service pipes provided. Under such conditions smaller tanks can be used than when the supply is from one or two streets only. When there is only one or two service pipes for a building housing a large number of people, and where interruption of water service is not to be permitted, there ought to be storage capacity on the premises for at least 48 hours supply of water. It is not likely that water service in the street mains will be interrupted for a longer period than that.

Part of the house supply can be carried in the house tanks, and the rest in the suction tank. The sizes of the tanks can then be proportioned to one another to suit conditions, so long as there is 48 hours supply of water available. For instance, if space would not permit the installation of large service or house tanks, the difference would have to be made up in the suction tank; while, on the other hand, if there was but little space for the suction tank, the house tanks would have to be large enough to care for the rest of the emergency supply.

The general arrangement of pipe connections to a house

tank is shown in Fig. 103. The cleanout or emptying pipe is valved and connected to the overflow pipe. The house supply extends a few inches above the bottom of the tank to prevent sediment entering the pipe. Below the valve that controls the house supply is connected a vent pipe to admit air to the house supply and permit it to empty when the valve is shut off. A vapor or relief pipe from the highest point in the hot water supply system bends over the tank and thus permits the escape of steam. The pump may discharge into the house tank in the manner indicated when the pump is not controlled automatically. When it is, the pump pipe should enter the tank through the bottom and be controlled by a balanced float valve. A drip pan, *a*, under the tank and extending a few inches on all sides of it, catches the water of condensation and discharges it through the waste pipe, *b*, into the overflow pipe. When a tank is supplied with water by a pump that is not automatic in operation, a tell-tale pipe should be run from a point in the tank about two inches below the level of the overflow pipe to the engineer's sink. Water flowing through the pipe then notifies the engineer when the tank is full.

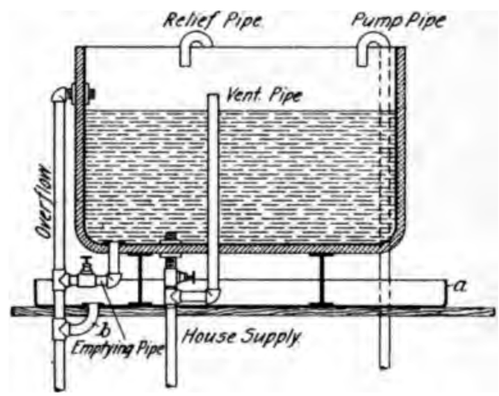


Fig. 103
House Tank

In all tall buildings the hot water line should have a relief valve at the house tank, otherwise hot water will flow from the relief pipe into the house tank. Owing to the water in the cold water down riser being heavier than the water in the hot water riser, the hot water will rise above the level of the water in the house tank.

COMPLETE MECHANICAL EQUIPMENT.—An illustration

of the complete mechanical equipment of a water supply system in a building supplied with street and tank pressure is shown in Fig. 104. Two separate water service pipes from mains in different streets are cross-connected before being connected to the meter, so that water from either or both street mains can be used. The meter is shown by-passed. Some water supply companies will not permit a by-pass around a meter, and where such a rule prevails another meter should be placed on the by-pass. From the meters the water passes to the filters, which are so con-

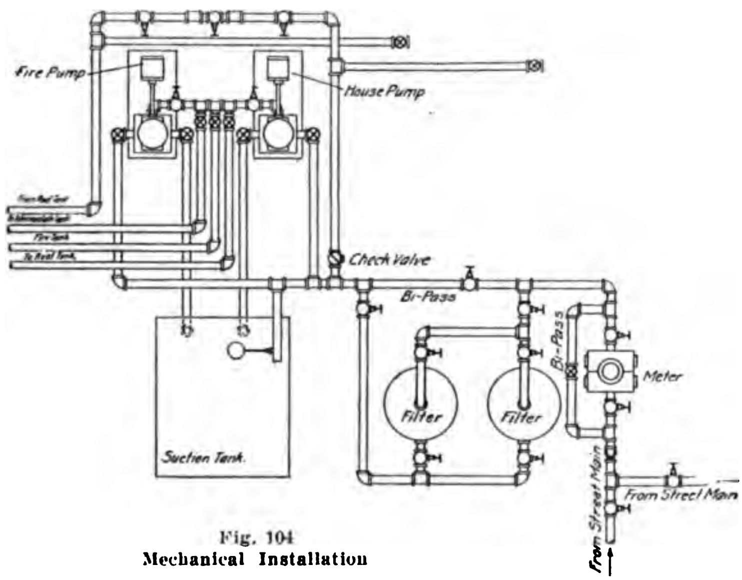


Fig. 104
Mechanical Installation

nected that they may be used either separately or together. A by-pass is provided around the filters, so water can be supplied direct to the building without filtration. After leaving the filters, one branch of the house main is connected to the cold water main for the lower floors, another branch supplies the hot water tank for the lower floors, still another branch supplies the suction tank through a balanced ball cock, and the remaining two branches are connected to the suction pipes of the two pumps, so they can pump direct from the city water mains. The pumps are also connected

by suction pipes to the suction tank from which they generally draw water. The supply pipe from the house tank is connected to the supply pipe from the street, at a point between the two cold water drums. A valve is there provided so that in case of necessity water from the house tank can be turned on to the lower water supply system. A check valve is placed where marked on the illustration, to prevent water from the house tank running off into the street mains or returning to the suction tank.

CHAPTER XXII

FIRE LINES

SYSTEM OF INSTALLATION.—Fire lines are now generally installed in all large buildings. A typical arrangement of pipes for fire service is shown in Fig. 105. In this system the lines are cross-connected, so that either the fire pump, the house pump, or both pumps can supply water in case of fire. A house tank on the roof keeps the lines full of water and provides a temporary supply while the pumps are being started. Branch lines extending through the building walls to the street terminate with siamese twin connections, through which water from street hydrants or fire engines can be forced into the system. The fire system is well supplied with soft seat check valves, so that water supplied from one source cannot be lost through other outlets. A check valve in the line of pipe connected to the tank prevents water from filling and overflowing the tank when supplied from pumps or twin connections. Checks in the lines leading to the twin connections prevent the loss of water from these outlets when water is supplied from either the pump or the tank, and check valves in the pump pipe relieve the pump valves of the pressure of water in the system. Emptying pipes are provided to drain the entire system, and separate pipes are provided to empty and thus prevent water freezing in the portions of pipe between the check valves in the cellar and siamese twin connections in the street. At each floor of the building 2½-inch outlets are left, to which are attached soft seat angle hose valves with 50 to 75 feet of underwriters' linen hose coiled on a reel or folded on a rack.

SIZES OF STANDPIPES.—For fire lines standpipes should be proportioned to the number of hose outlets they supply. The size of opening in hose nozzle for hose of 2½ inches diameter seldom exceeds 1¼ inches in diameter, and if

allowance of the sectional area of a 2-inch pipe be made for each hose outlet in the building, both sufficient volume and pressure will be provided to throw an effective fire stream when all the nozzles are being used.

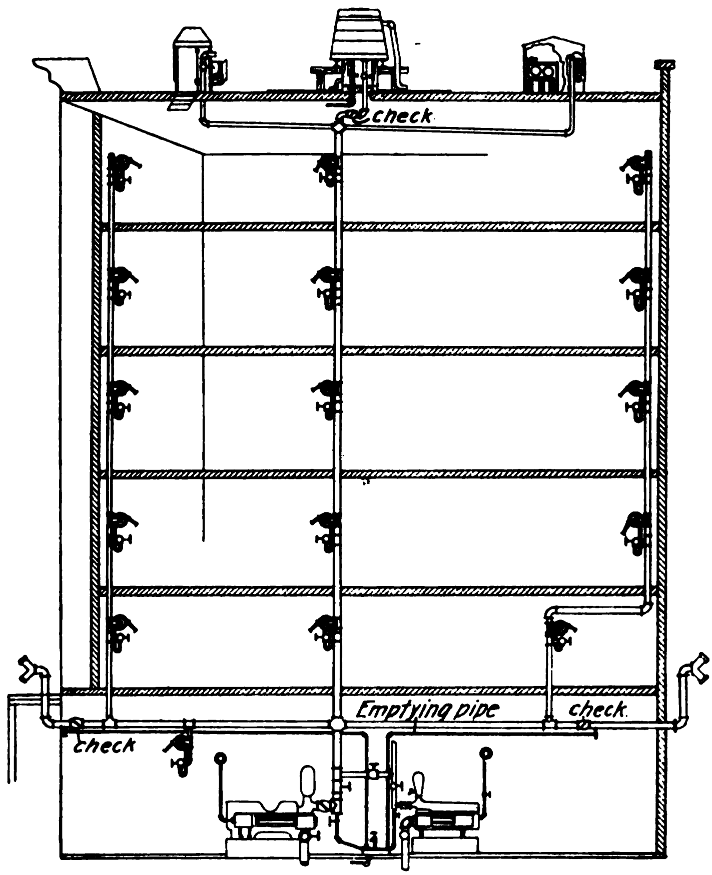


Fig. 105
Fire Lines

RANGE OF FIRE STREAMS.—The extreme distance water can be thrown both horizontally and vertically, and the distance the streams will be effective for fire purposes under different heads and through different sizes of nozzles, are shown in Table LVI.

TABLE LVI. Range of Fire Streams

BY JOHN R. FREEMAN, M. E.

Pressure at Nozzle	Gallons Discharged Per Min.	Vertical Distance of Stream	Horizontal Distance of Stream	Pressure in pounds required at Hydrant or Pump to maintain pressure at nozzle through various lengths of 2½-inch smooth rubber-lined hose. 50 ft.	100 ft.	200 ft.	300 ft.	400 ft.	500 ft.	600 ft.	800 ft.	1000 ft.
				¾ INCH SMOOTH NOZZLE								
35	97	55	41	37	38	40	42	44	46	48	53	57
40	104	60	44	42	43	46	48	50	53	55	60	65
45	110	64	47	47	48	51	54	57	59	62	68	73
50	116	67	50	52	54	57	60	63	66	69	75	81
55	122	70	52	58	59	63	66	69	73	76	83	89
60	127	72	54	63	65	68	72	76	79	83	90	97
65	132	74	56	68	70	74	78	82	86	90	98	106
70	137	76	58	73	75	80	84	88	92	97	105	114
75	142	78	60	79	81	85	90	94	99	104	113	122
80	147	79	62	84	86	91	96	101	106	111	120	130
85	151	80	64	89	92	97	102	107	112	117	128	138
90	156	81	65	94	97	102	108	113	119	124	135	146
95	160	82	66	99	102	108	114	120	125	131	143	154
100	164	83	68	105	108	114	120	126	132	138	150	163
				⅞ INCH SMOOTH NOZZLE								
35	133	56	46	38	40	44	48	52	56	60	68	76
40	142	62	49	43	46	50	55	59	64	68	78	87
45	150	67	52	49	51	57	62	67	72	77	87	97
50	159	71	55	54	57	63	69	74	80	86	97	108
55	166	74	58	60	63	69	75	82	88	94	107	119
60	174	77	61	65	69	75	82	89	96	103	116	130
65	181	79	64	71	74	82	89	96	104	111	126	141
70	188	81	66	76	80	88	96	104	112	120	136	152
75	194	83	68	82	86	94	103	111	120	128	145	162
80	201	85	70	87	91	101	110	119	128	137	155	173
85	207	87	72	92	97	107	116	126	136	145	165	184
90	213	88	74	98	103	113	123	134	144	154	174	195
95	219	89	75	103	109	119	130	141	152	163	184	206
100	224	90	76	109	114	126	137	148	160	171	194	216

TABLE LVI—Continued

Pressure at Nozzle	Gallons Discharged Per Min.	Vertical Distance of Stream	Horizontal Distance of Stream	Pressure in pounds required at Hydrant or Pump to maintain pressure at nozzle through various lengths of 2½-inch smooth rubber-lined hose.								
				50 ft.	100 ft.	200 ft.	300 ft.	400 ft.	500 ft.	600 ft.	800 ft.	1000 ft.
1 INCH SMOOTH NOZZLE												
35	174	58	51	40	44	51	57	64	71	78	92	105
40	186	64	55	46	50	58	66	73	81	89	105	120
45	198	69	58	52	56	65	74	83	91	100	118	135
50	208	73	61	57	62	72	82	92	102	111	131	151
55	218	76	64	63	69	79	90	101	112	122	144	166
60	228	79	67	69	75	87	98	110	122	134	157	181
65	237	82	70	75	81	94	107	119	132	145	170	196
70	246	85	72	80	87	101	115	128	142	156	183	211
75	255	87	74	86	94	108	123	138	152	167	196	226
80	263	89	76	92	100	115	131	147	162	178	209	241
85	274	91	78	98	106	123	139	156	173	189	222	...
90	279	92	80	103	112	130	147	165	183	200	236	...
95	287	94	82	109	118	137	156	174	193	211	249	...
100	295	96	83	115	125	144	164	183	203	223	...	...
1⅛ INCH SMOOTH NOZZLE												
35	222	59	54	43	49	60	71	82	94	105	127	149
40	238	65	59	50	56	69	81	94	107	120	145	171
45	252	70	63	56	63	77	92	106	120	135	163	192
50	266	75	66	62	70	86	102	118	134	150	181	213
55	279	80	69	68	77	95	112	130	147	165	200	235
60	291	83	72	74	84	103	122	141	160	180	218	256
65	303	86	75	81	91	112	132	153	174	195	236	...
70	314	88	77	87	98	120	143	165	187	209	254	...
75	325	90	79	93	105	129	153	177	201	224	...	...
80	336	92	81	99	112	138	163	188	214	239	...	...
85	346	94	83	106	119	146	173	200	227	254	...	...
90	356	96	85	112	126	155	183	212	241	...	...	...
95	366	98	87	118	133	163	194	224	254	...	...	...
100	376	99	89	124	140	172	204	236	...	...	...	...

TABLE LVI—Continued

Pressure at Nozzle	Gallons Discharged Per Min.	Vertical Distance of Stream	Horizontal Distance of Stream	Pressure in pounds required at Hydrant or Pump to maintain pressure at nozzle through various lengths of 2½-inch smooth, rubber-lined hose.								
				50 ft.	100 ft.	200 ft.	300 ft.	400 ft.	500 ft.	600 ft.	800 ft.	1000 ft.
1¼ INCH SMOOTH NOZZLE												
35	277	60	59	48	57	74	91	109	126	142	178	212
40	296	67	63	55	65	84	104	124	144	164	203	243
45	314	72	67	62	73	95	117	140	162	184	229	...
50	331	77	70	68	81	106	130	155	180	204	254	...
55	347	81	73	75	89	116	143	170	198	225	...	...
60	363	85	76	82	97	127	156	186	216	245	...	...
65	377	88	79	89	105	137	169	201	234	...	...	...
70	392	91	81	96	113	148	182	217	252	...	...	...
75	405	93	83	103	121	158	195	232	...	...	...	...
80	419	95	85	110	129	169	208	248	...	...	...	...
85	432	97	88	116	137	179	221	...	...	...	...	...
90	444	99	90	123	145	190	234	...	...	...	...	...
95	456	100	92	130	154	201	247	...	...	...	...	...
100	468	101	93	137	162	211	261	...	...	...	...	...
1⅜ INCH SMOOTH NOZZLE												
35	340	62	62	54	67	94	120	146	172	198	250	...
40	363	69	66	62	77	107	137	166	196	226	...	...
45	385	74	70	70	87	120	154	187	221	254	...	...
50	406	79	73	78	96	134	171	208	245	...	...	...
55	426	83	76	86	106	147	188	229	270	...	...	...
60	445	87	79	93	116	160	205	250	...	...	...	...
65	463	90	82	101	125	174	222	...	...	...	...	...
70	480	92	84	109	135	187	239	...	...	...	...	...
75	497	95	86	117	145	200	256	...	...	...	...	...
80	514	97	88	124	154	214	...	...	...	...	...	...
85	529	99	90	132	164	227	...	...	...	...	...	...
90	545	100	92	140	173	240	...	...	...	...	...	...
95	560	101	94	148	183	254	...	...	...	...	...	...
100	574	103	96	156	193	...	...	...	...	...	...	...

The pressures given are indicated pressures, not effective pressures. Effective pressures would be slightly greater.

The horizontal and vertical distances given, are for good, effective fire streams. The distances to which isolated drops would be thrown are very much greater.

The pressures stated are based on the hose being coupled directly to the pump or the hydrant and while the stream is flowing.

SIAMESE TWIN CONNECTIONS.—A Siamese Twin Connection is shown in Fig. 106. A flap valve, *a*, closes one opening when pressure is applied to the other, and stands open as shown in the illustration when water is being forced throught both openings.

FIRE HOSE.—A very convenient hose for use in short lengths in buildings is underwriters' linen hose. It will withstand almost any pressure likely to be subjected to and, being flexible, can be neatly coiled or folded into a very small space. The size of hose generally used for this purpose is 2½ inches diameter. For lengths of more than 25 feet, for real fire fighting, a smooth rubber-lined hose is the best to use, and in no case should the hose be less than 2½ inches in diameter, if it is 50 feet or longer, for a smaller hose will have only about one-half the effective range. For instance, with 80 pounds pressure, 250 feet of 2½-inch unlined linen hose will have an effective height of stream of 42 feet, while under the same pressure, and with the same length, a 2-inch unlined linen hose will have an effective height of only 20 feet.

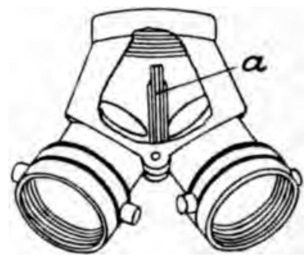


Fig. 106
Siamese Twin Connection

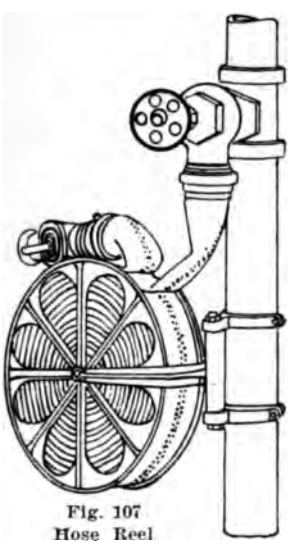


Fig. 107
Hose Reel

The superiority of smooth-lined hose over rough linen hose, for fire protection, also the loss in range due to friction in long lengths of hose can be judged from the following statement based on experiments, where the static pressure was 80 pounds, and pressure at the hydrant when the hose was playing, 70 pounds per square inch. With a 1⅛-inch nozzle, the heights of effective fire streams were;

With 50 feet of $2\frac{1}{2}$-inch linen hose......... 73 feet
With 250 feet of $2\frac{1}{2}$-inch linen hose......... 42 feet
With 500 feet of $2\frac{1}{2}$-inch linen hose......... 27 feet
With 50 feet of best and smoothest $2\frac{1}{2}$-inch rubber lined hose......................... 81 feet
With 250 feet of best and smoothest $2\frac{1}{2}$-inch rubber lined hose......................... 61 feet
With 500 feet of best and smoothest $2\frac{1}{2}$-inch rubber lined hose......................... 46 feet

This shows the importance of having fire lines sufficiently large to maintain a high pressure and supply a large volume of water when all the outlets are in use, and having the fire lines at such points that long lines of hose will not be required.

HOSE REELS.—Each length of hose should be neatly folded or coiled on a rack or hose reel provided for that purpose and attached to the wall or fire pipes close to the valve outlet. A swing hose reel is shown in Fig. 107. It is supported from the fire stand-pipe by a hinged clamp that permits the reel to turn in many directions. A $1\frac{1}{8}$-inch smooth nozzle is the best to use in connection with fire lines.

PART III
PURIFICATION OF WATERS

CHAPTER XXIII
FILTRATION

Rapid Sand Filtration

THEORY OF FILTRATION.—Water for municipal supply may be classed, according to the source from which it is obtained, as surface water or as ground water. Waters obtained from streams, rivers, lakes, or impounding reservoirs are surface waters; generally such waters are soft, and when filtered are the best kind of waters for both domestic and for industrial purposes. As surface water exists in nature, however, it is never organically pure and seldom clear; it generally carries considerable matter both in suspension and in solution and sometimes is contaminated by specific germs of disease. The amount of suspended matter in surface water varies considerably, being greatest after heavy rains which wash the finely divided soil and earth down into streams, lakes and reservoirs. Water that contains large quantities of matter in suspension is unsuitable for domestic and for most industrial purposes and should be filtered before using.

FILTRATION.—Filtration is both a straining and a biological process in which most of the suspended matter and part of the hardness, color, and organic matter in raw water are removed. This is effected by passing the raw water through a thick bed of fine sand that is covered by a still finer jelly-like layer which entangles and holds any suspended matter brought in contact with it. The efficiency of a filter depends largely on this jelly-like layer, and a filter is not at its best until a suitable layer has formed. Under ordinary conditions to naturally form such a layer would take about twenty days, and to obviate such delay and bring a filter to its full bacterial efficiency in from

twenty to thirty minutes, coagulants are used to artificially produce the jelly layer.

The coagulants generally used are sulphate of alumina (common alum) and sulphate of iron. When sulphate of alumina is added to water it decomposes into its component parts, sulphuric acid and alumina; the sulphuric acid combines with lime, magnesia, or any other base present in the water, while the alumina forms a flaky precipitate that gathers together and holds whatever suspended matter it encounters, thus forming in a few hours a layer that without the use of coagulant would require weeks to form. The thicker the layer of sediment, the greater the bacterial efficiency of a filter, but usually after from twelve to twenty-four hours' operation, the sediment layer becomes so thick that sufficient water cannot pass through, and the filter bed must then be cleaned.

GRAVITY TYPE FILTER.—A filter of the subsidence gravity type is shown in Fig. 108. Unfiltered water, to which coagulant has been added, enters the subsidence basin beneath the filter and usually tangent to the circumference, as experiment has demonstrated that a rotary motion conduces to greater and more rapid sedimentation. From the subsidence basin water rises through the hollow vertical axis, *h*, and overflows to the filter bed through which it percolates to the system of under drains below. The copper float, *a*, in the filter tank automatically regulates the supply of water and thus maintains a uniform head, while the automatic controller, *e*,

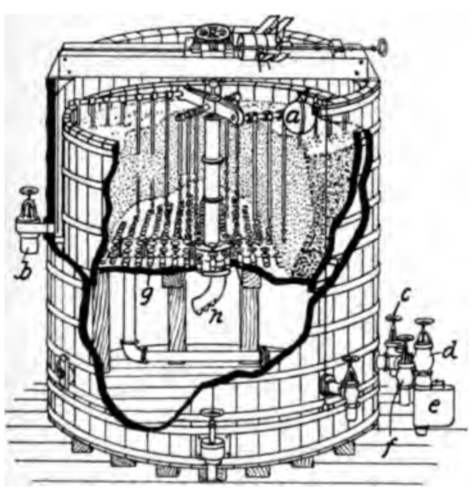


Fig. 108
Gravity Filter

on the outlet or pure water pipe regulates the rate of filtration.

When the filter bed is dirty it is cleaned by reversing the flow of water through the filter bed and thoroughly loosening the sand. This is effected by pumping filtered water into the sand bed through the outlet pipe, and when the sand is thoroughly loosened revolving the iron rakes, thus breaking up the jelly layer on top of the sand and stirring up the entire filter bed so all the grains of sand will be exposed to the scouring action of the water. The wash water and dirt from the filter bed overflow the filter tank into the annular space between the two tanks, and are carried out through the valve, *b*, to the sewer. For a few minutes after a filter bed is washed, its efficiency is greatly lowered, so for a short time after starting, the water is allowed to filter to waste through the valve, *c*. After sufficient water has run to waste to insure a good filtrate, valve *c* is closed, valve *d* opened and filtered water discharged to the clear water tank through the controller, *e*. To clean the filter bed, valves *c* and *d* are closed, valve *f* opened and air and water alternately forced through the system of collectors, *g*, to the filter bed.

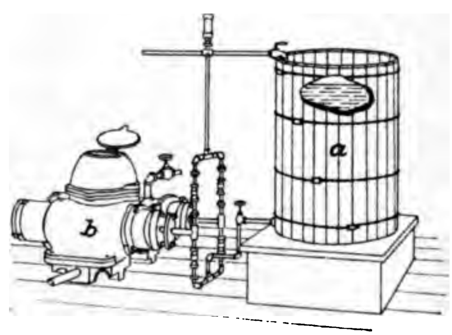


Fig. 109
Coagulant Pump

COAGULANT PUMP.—To secure the best results the amount of coagulant used must be proportioned to the condition of the water; the amount varies from one-quarter grain to two grains per gallon, the exact amount for any water being determined by experiment. If sufficient coagulant is not fed to the raw water, it will result in an inferior filtrate, and if too much coagulant is used, it will not only increase the cost of operation, but coagulant will pass through the filter bed to the delivery mains. Some waters

are so soft that insufficient base is present for coagulant to react upon. When such is the case, a base, usually of lime, is also added to the raw water.

To feed coagulant to the raw water, some form of pump or apparatus is required that will be automatic in operation and feed a measured quantity of coagulant proportional to the quantity of water. A meter pump for this purpose is shown in Fig. 109. A coagulant solution of the required strength is mixed in wooden coagulant tank, *a*, which is connected by feed pipes to a meter-actuated duplex pump, *b*.

The meter measures the quantity of raw water passing through; the raw water operates the pumps which discharge a proportional quantity of solution into the raw water. All working parts of a pump or other coagulant apparatus should be made of bronze to withstand the corroding effects of sulphate of alumina or sulphate of iron, which energetically attacks and destroys iron.

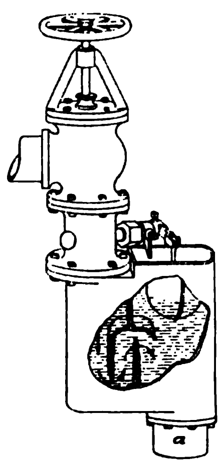


Fig. 110
Filtration Controller

FILTRATION CONTROLLERS.—After filter beds have been cleaned the rate of filtration, for a while, is much faster than at other times, and is often too great for efficient results. Under working conditions an excessive rate of filtration might disturb the jelly layer and permit raw water to pass through with but little filtration. To regulate the rate of filtration, automatic controllers, Fig. 110, are now generally used. In this type of controller the outlet is fitted with removeable bushings that regulate the discharge to the desired velocity; if the rate of filtration then becomes greater than can be discharged, water will fill the controller box and raise the float, thus throttling the balance valve and reducing the flow to the required rate.

EFFICIENCY OF GRAVITY FILTERS.—The bacterial efficiency of gravity filters depends upon the use of coagulants.

If clear water for industrial purposes is wanted, it may be had by filtering though sand without coagulant, but for domestic water supply, where bacterial purity is required,

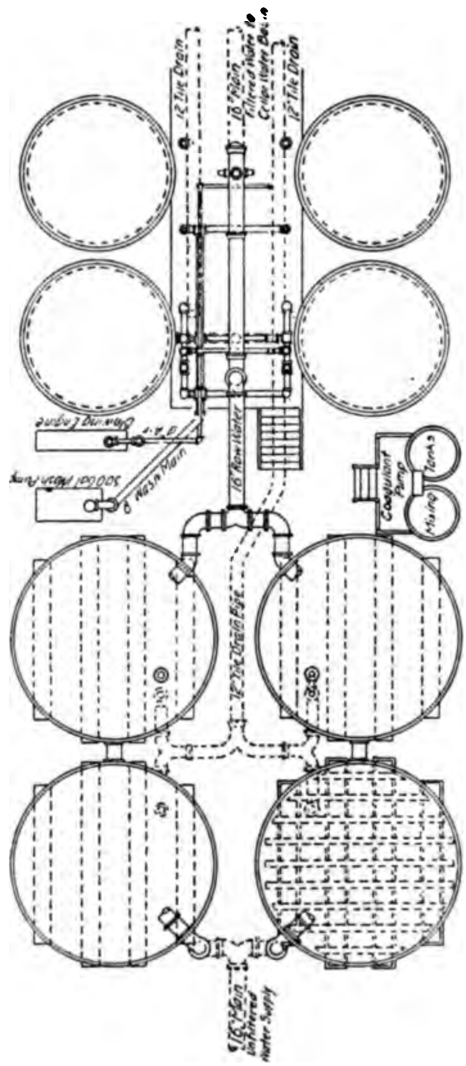


Fig. 111
Plan of Filtration Plant

coagulants must be used. The tabulated report of chemical and bacterial tests of gravity water filters, at Lorain,

TABLE LVII. Efficiency of Filters

Date March, 0000	Hour	Bacteria per C. C. Applied Water	Bacteria per C. C. Filtered Water	Percentage Reduction Efficiency Filters	Parts per Million: Alkalinity Applied Water	Parts per Million: Alkalinity Filtered Water	Parts per Million: Ferrous Iron Fe. Filtered Water	Parts per Million: Caustic Lime CaO. Filtered Water	Parts per Million: Chlorine Applied Water	Parts per Million: Turbidity Applied Water	B. Coli. Communis Applied Water	B. Coli. Communis Filtered Water	Amount of Ferrous Sulphate Used Grains per Gallon	Amt. of Caus. Lime Used. Grs. per Gal.	Gallons of Water Filtered
7th	1.15 p. m.	76,860	248	99.67	78.0	77.0	None	None	17.5	200	Present	Absent	2.52	.64	3,498,600
7th	4.00 p. m.	93,330	310	99.66											
7th	5.00 p. m.	109,800	222	99.79											
7th	9.30 p. m.	97,720	198	99.79											
8th	11.00 a. m.	54,900	590	98.82	79.0	70.0	None	None	15.0	200	Present	Absent	2.96	.56	3,447,640
8th	1.00 p. m.	48,730	184	99.62											
8th	2.30 p. m.	46,810	280	99.40											
8th	5.30 p. m.	52,780	230	96.56											
9th	12.00 m.	27,450	230	99.16	81.0	70.0	None	None	14.0	140	Present	Absent	2.99	.56	3,493,700
9th	2.15 p. m.	26,460	94	99.64											
9th	4.00 p. m.	28,110	190	99.32											
9th	5.00 p. m.	27,840	130	99.53											
10th	7.00 a. m.	56,700	142	99.74	81.0	72.0	None	None	16.0	140	Present	Absent	2.62	.56	3,451,660
10th	8.20 a. m.	57,900	112	99.80											
10th	11.00 a. m.	55,800	184	99.67											
10th	2.00 p. m.	53,760	210	99.60											
11th	1.00 p. m.	40,530	104	99.74	82.0	78.0	None	None	14.5	130	Present	Absent	2.80	.57	3,441,800
11th	5.00 p. m.	38,760	128	99.66											
11th	7.00 p. m.	35,400	72	99.79											
11th	9.30 p. m.	33,300	96	99.71											
12th	4.00 p. m.	46,710	140	99.70	84.0	82.0	None	None	18.0	60	Present	Absent	2.67	.60	3,312,400
12th	5.00 p. m.	47,700	38	99.92											
12th	7.00 p. m.	48,600	116	99.75											
12th	9.00 p. m.	49,830	134	99.73											
Avge.		52,292	182	99.65	81.0	74.8	None	None	15.8	145	Present	Absent	2.76	.58	3,424,300

Remarks—Filtered water in perfect physical condition, being free of turbidity and color and very brilliant and sparkling. Average rate, 110,010,000 gallons per acre.

As will readily be seen, this has been a week of bad water. The large number of bacteria in the applied water, in connection with large sewage contamination, have made obligatory a larger use of chemicals than is necessary under normal conditions. Turbidity and chlorine contents have also been high.

With sulphate of iron at $9.00 per ton and caustic lime at $5.00 per ton, the chemical cost for the week would average $1.77 for iron and 21 cents for lime: total, $1.98 per 1,000,000 gallons filtered.

It has been shown by rather extensive experiments conducted at this station that to accomplish the same work with alum there is required fully as much alum as iron sulphate, and with high turbidities a trifle freer use of alum obtains. It is probable, therefore, that an average use of 3 grains of alum per gallon would have been necessary to get the same percentage reduction. With alum at $20.00 per ton, the cost would have been $4.25 per million filtered, or a saving of $2.30 per 1,000,000 gallons filter in favor of the iron process.

(Signed) C. ARTHUR BROWN, Superintendent.

Ohio, given in Table LVII, will serve to show the efficiency of rapid sand filters.

A plan of a filter house for a small city plant, showing the layout of filters, piping and apparatus, is illustrated in Fig. 111.

PRESSURE FILTERS.—Pressure filters are enclosed in water-tight chambers, so that water can be driven through the filter bed by hydraulic pressure. A Jewell pressure filter of the settling basin type is shown in Fig. 112. This filter is constructed and operated similar to the Jewell gravity type, from which it differs only by being enclosed in a water-tight case. Pressure filters are not as efficient as gravity filters, but owing to the ease with which they can be attached to a water supply system they are extensively used for house filters. Usually pressure filters are connected to the service pipe in the cellar, and all water used in the building passes through them. When so installed they should be provided with a by-pass to permit unfiltered water being supplied to fixtures in the building in case the filter is cut out. The bacterial efficiency of pressure filters like that of gravity filters depends upon the use of coagulants. When water is to be used for manufacturing purposes, however, a clear filtrate can be obtained without coagulants. An automatic apparatus is used to feed coagulant to pressure filters.

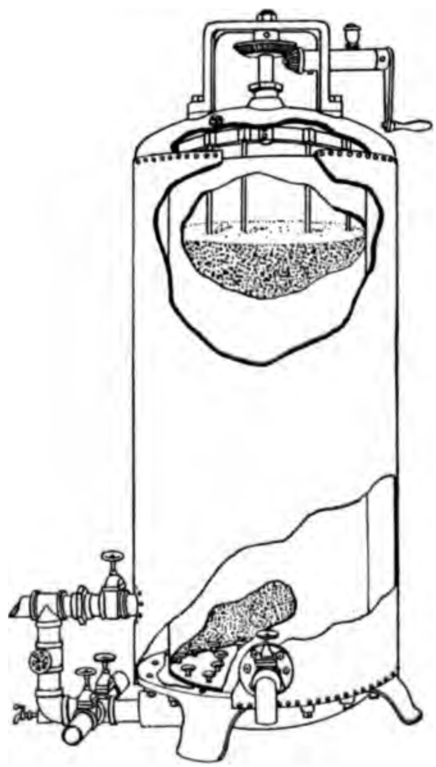


Fig. 112
Pressure Filters

CHAPTER XXIV
SOFTENING OF WATER

ECONOMY OF SOFT WATERS.—Throughout the Mississippi Valley and in other parts of the United States where municipal water supplies are obtained from artesian wells drilled to the underlying St. Peter or Potsdam sandstone, the water is permanently, and in some localities, both temporarily and permanently hard. This is due to the fact that in those regions the geological formation of the upper strata is limestone, and in percolating through the limestone, the water, which originally was soft, dissolves from rock, carbonates or sulphates of lime or magnesia. The solvent capacity of water for carbonates and sulphates of lime is greater when the water is cold; therefore, deep well waters in limestone regions usually are saturated with lime or magnesia, and when heated in water tanks or boilers to a temperature greater than 140 degrees Fahrenheit, the point of saturation is lowered and lime is precipitated or liberated and forms a hard scale or incrustation in waterbacks and boilers. The effect of boiler incrustation is to shorten the life of a boiler and decrease the efficiency of the apparatus while in service.

It is accepted by good authority that:

1/16-inch lime scale means a loss of 13 per cent. of fuel.
1/8-inch lime scale means a loss of 22 per cent. of fuel.
1/4-inch lime scale means a loss of 38 per cent. of fuel.
3/8-inch lime scale means a loss of 50 per cent. of fuel.
1/2-inch lime scale means a loss of 60 per cent. of fuel.
3/4-inch lime scale means a loss of 91 per cent. of fuel.

These values are probably a little high, but making due allowance for inaccuracies the table still serves to show the enormous waste of coal due to boiler incrustation.

Incrustation of waterbacks and water heaters not only decreases their efficiency while in service, but is also a source of expense for repairs. In limestone regions waterbacks and heaters become choked with lime and require

cleaning at certain intervals of time ranging from one to six months.

In the household, the increased consumption of soap to soften hard water is a further item of expense. The amount of commercial soap required for this purpose, with waters of different degrees of hardness, can be seen in Table LVIII.

TABLE LVIII. Soap Required to Soften Water

Gallons of Water	1° Hardness Soap Pounds	3° Hardness Soap Pounds	4° Hardness Soap Pounds	8° Hardness Soap Pounds	12° Hardness Soap Pounds	16° Hardness Soap Pounds
100	0.119	0.357	.476	.952	1.428	1.904
1,000	1.19	3.57	4.76	9.52	14.28	19.04
10,000	11.90	35.7	47.6	95.2	142.8	190.4
100,000	119.00	357.	476.	952.	1428.	1904.
1,000,000	1190.00	3570.	4760.	9520.	14280.	19040.

Many industrial concerns, like breweries, paper mills, distilleries, refineries, ice factories and laundries, require soft water, not only for boiler feed, but also for industrial purposes, and use some modification of the Clark-Porter water softening process.

The Clark process consists of adding lime water to temporarily hard water to remove the carbonates of lime or magnesia. The lime acts upon the bicarbonates in the hard water, releasing the extra carbonic acid gas required to form the bicarbonates, and precipitates the carbonates of lime which are insoluble.

The Porter process consists of adding soda ash to permanently hard water to remove the sulphates of lime and magnesia, and stirring up the treated water with paddles to mix it. When soda ash is added to permanently hard water, it reacts upon the sulphates of lime and magnesia, decomposes them and forms insoluble carbonates which are precipitated.

The reagents generally used in water softening are caustic lime (common quick lime) and soda ash. Other reagents can be used, but the above are generally selected

on account of their cheapness and because they are readily obtainable in any market.

WATER SOFTENING APPARATUS.—An apparatus for softening water consists of a mixing chamber for the chemical reagents, a settling basin for the treated water after the reagent is added and a filter to remove from the softened water the base acted upon by the chemical.

There are two general arrangements of apparatus for softening water. One arrangement is known as the closed or pressure system, and the other arrangement, as the gravity system.

The general arrangement of the Scaife pressure system as used for softening feed water for boilers is shown in Fig. 113.

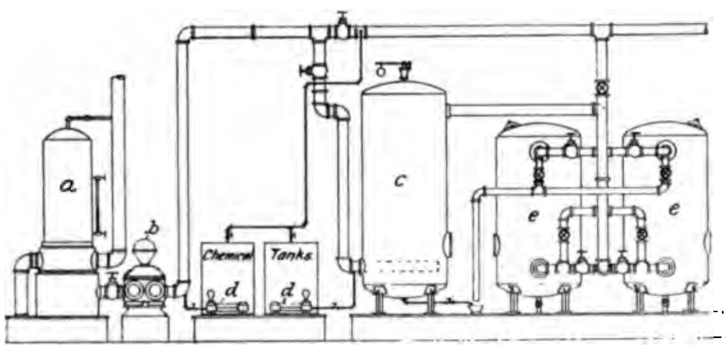


Fig. 113
Pressure Water Softening System

Feed water enters the open heater, *a*, where some of the temporary hardness is removed by raising the temperature to 200 or 210 degrees Fahrenheit, thus driving off some of the free carbonic acid gas and precipitating carbonates of lime and magnesia on removable pans inside of the heater. From the heater the water is forced by the boiler feed pump, *b*, into a large precipitating tank, *c*, where the chemical reagents are introduced by means of two small pumps, *d*, *d*. In the precipitating tank most of the remaining carbonates and sulphates of lime and magnesia are precipitated; some of the lighter particles, however, are carried

in suspension to the filters, *e, e,* where along with other impurities they are removed.

When this system is used for industrial or for domestic purposes, the heater and feed water pumps may be omitted and the hard water discharged directly into the precipitat-

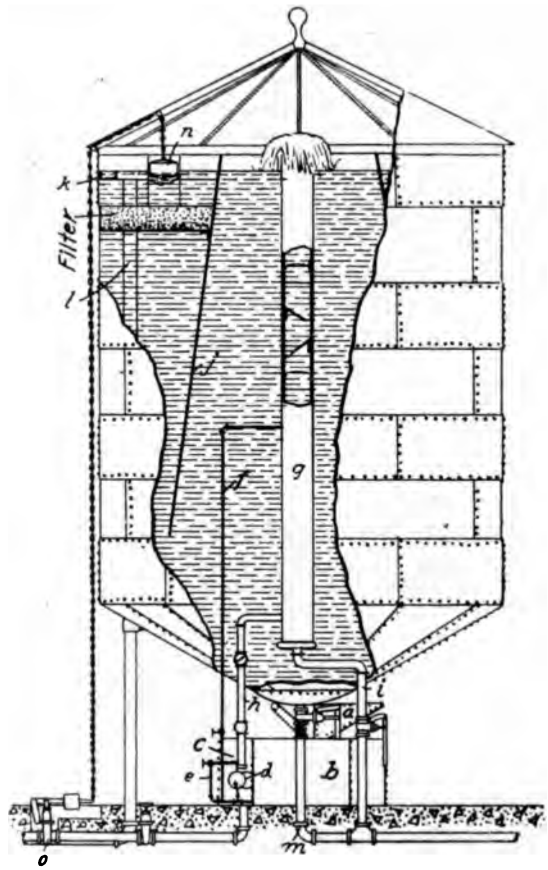


Fig. 114
Gravity Water Softening Apparatus

ing tank. When the heater is omitted, however, a larger quantity of reagent is required.

A gravity apparatus for water softening is shown in Fig. 114. In this system of treatment, lime is slacked in the trough, *a*, after which it is emptied into the saturator, *b*,

where it can be diluted to the required consistency and be kept agitated by revolving paddles. In a tank, *c*, a solution of soda ash is prepared, which, like the lime solution, is agitated by revolving paddles operated by the water motor, *d*. Lime solution is fed to the raw water through pipe *e*. and soda solution is fed to the raw water through pipe *f*. By means of an automatic proportional water motor, a measured quantity of water and proportional amounts of either lime, soda, or both lime and soda, are introduced into the standpipe, *g*, the water flowing in through pipe, *h*. Baffle plates in the standpipe thoroughly mix and agitate the treated water, thus aiding precipitation. The lime deposited in standpipe, *g*, is washed out through the valved pipe, *i*. The treated water overflows the top of the standpipe, passes under the baffle plate, *j*, up through the filters and overflows through trough, *k*, and pipe, *l*, to a collecting or storage reservoir. Sludge from precipitation in the tank settles to the cone-shaped bottom and is washed out through pipe, *m*. A float, *n*, controls the supply valve, *o*, thus making the apparatus automatic in operation.

When the water to be treated is obtained from a stream or other surface source where the conditions of the water are not uniform, it is better to use an intermittent type of apparatus. By this system a large quantity of water is put in a tank and treated; while that tank is being emptied, a second tank is filled, the water tested and the right proportion of reagent mixed to treat it. In this manner each tank of water is separately tested and the correct proportion of chemicals added.

THE PERMUTIT PROCESS OF SOFTENING WATER.—The Permutit process for softening water is simple of operation and applicable for both domestic and industrial uses. The softening is accomplished automatically by passing the hard water through a tank, as shown in Fig. 115, containing porous but insoluble crystals of aluminum-sodium silicate, where an exchange takes place between the lime and magnesia in the water, and the sodium forming the base of the crystals.

When the sodium base of the Permutit becomes ex-

hausted, as it does after a given quantity of water has been softened by it, it is necessary to renew the sodium. This is done by adding a solution of common salt to the Permutit, which by mass action drives out the calcium and magnesium, leaving sodium in their place. The calcium and magnesium salts are run off through the drain pipes. This process can be carried on indefinitely, as the life of the Permutit is unlimited. The only cost of operation is the cost of common salt. Usually the regenerating process, as it is called, is carried on at night.

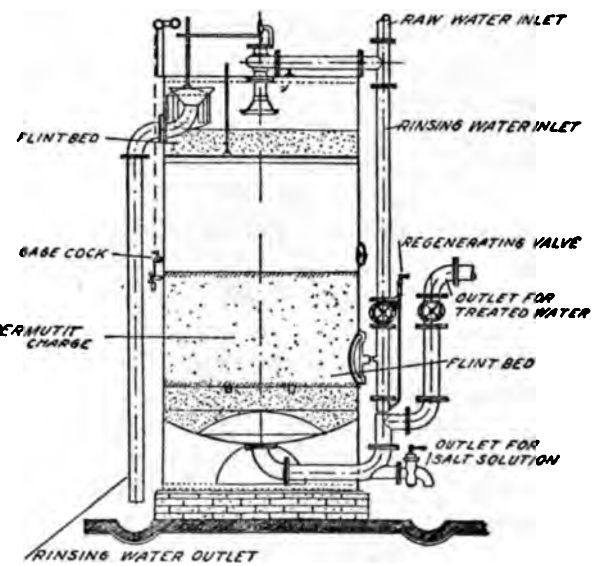


Fig. 115
Permutit Apparatus for Softening Water

The regenerating solution generally used contains about 10 per cent. of sodium chloride (common salt). This reaction also obeys the law of mass action, and since the Permutit has a greater affinity for calcium than for sodium, three to four times as much salt as is theoretically required is provided, and further to facilitate the action the solution is usually heated to 100 to 120 degrees Fahrenheit.

Admission of the solution to the filter is regulated automatically at a very slow rate to permit the solution thor-

oughly to penetrate the grains or zeolites. Admission occupies 4 to 5 hours and, when the charge is completely impregnated the solution is left in the filter for about the same period. The charge is then drained and washed thoroughly to remove all traces of salt. Since the regenerative process is completed in about 8 hours, the installation of one filter will satisfy the demands of the ordinary plant, but where continuous service is required two filters will be necessary for alternate softening and regeneration.

DATA OF OPERATION.—Water of any degree of hardness may be softened by passing it through a layer of Permutit 24 to 40 inches in depth at a rate of 10 to 16 feet an hour; and the speed of filtration usually adopted lies between these limits. The permissible speed of filtration can be raised by increasing the depth of Permutit charge, but it is limited by the fact that for efficient action the water must have time to penetrate the interior of the grains. The extreme limits of speed are: for water containing 0.01 per cent. lime, approximately 27 feet; 0.02 per cent., 16 feet; and 0.03 per cent., 10 feet an hour. The volume of water treated depends, of course, on the area of the charge.

The filtering apparatus shown in the illustration is of the gravity type, but a closed type for pressure working is employed in some cases. In either type, the charge of Permutit rests on a bed of crushed flint and a similar bed of flint, carried on a perforated plate, is placed in the upper part of the filter to prevent the escape of Permutit during the regenerative process.

The principle of operation of the Permutit process is based on the peculiar properties of zeolites. Natural zeolites are combinations of aluminum and other bases with silicic acid. The peculiarity of zeolites is the property of changing their bases for others. That is, a zeolite formed of silica, aluminum and sodium or salt can exchange its base of salt for a base of lime or magnesia; and this property is made use of in the softening of water by the Permutit process.

The zeolites used are artificial, and in the moist condition are of a granular or flaky form with a lustre like that

of mother-of-pearl. Owing to its porosity, in the dry state the material readily absorbs about 50 per cent. of water, and must therefore be stored in a dry place safe from frost.

The water flowing to Permutit water softener must be clear, free from iron and mechanical impurities, and the temperature should not be more than 100 degrees Fahrenheit.

The artificial zeolites used in this process are obtained by fusing together feldspar, kaolin, clay and soda in definite proportions. It will be seen, therefore, that they partake of the nature of a very porous earthenware or porcelain.

CHAPTER XXV
STERILIZING WATER WITH ULTRA VIOLET RAYS

The sterilization of water by means of the ultra violet rays is based on the well-known germicidal action of sunlight. What is known as the white light of the sun is really the result of a blend of all colors of the rainbow. This white light can be broken up into its component parts by passing a beam of the light through a triangular glass prism which gives the solar spectrum.

Of the visible colors, the blue or violet is at one end of the spectrum, and the red at the other extreme. Beyond the visible spectrum are invisible light waves known as the ultra rays. Beyond the violet rays are the ultra violet rays, which of course are invisible.

All light is due to wave vibrations. The difference in color is due to a difference in wave length. Of the visible colors the shortest are those of the violet. Just beyond the violet the ultra violet waves are even shorter and more intense in their vibrations.

The ultra violet rays are the most destructive to bacterial life. The well-known sterilizing action of sunlight is due to the short wave vibrations of the violet, ultra violet and other rays it contains.

The exact action or reaction which proves so destructive to bacterial life is not known. It is believed, however, that the ultra violet rays first produce a coagulation of the protoplasm, which results finally in an entire disappearance of the body of the germ. Exhaustive tests show that the bacteria are killed, not merely shocked into a dormant state with the possibility of future recovery. They also show that the bacterial destruction is due directly to the ultra violet rays, not through the medium of oxidation by chemicals formed by the contact of the rays with the water, nor by any other indirect means. The temperature of the water has no effect on this bacterial action. The same germicidal

action is found when clear ice is subjected to ultra violet rays as when water of any temperature is exposed.

It requires only a comparatively short time for ultra violet rays to exercise their germicidal action on water-borne bacteria. The approximate length of exposure to the ultra violet rays required for complete destruction can be found in Table LIX.

TABLE LIX. Time Required for Ultra Violet Ray Sterilization

Kind of Bacteria	Exposure Required for Complete Sterilization
Staphylococcus Aureus	12 Seconds
B. Cholera	17 Seconds
B. Typhoid	18 Seconds
B. Dysentery (Shigo)	17 Seconds
B. Dysentery (Dopter)	16 Seconds
B. Coli	18 Seconds
Aerogenes Capsulatus	21 Seconds
B. Tetanus	40 Seconds

The depth of water that ultra violet rays will sterilize depends upon the strength of the light and length of exposure. In practice, as the exposure must be comparatively short, the film of water must be correspondingly thin. In ultra violet ray sterilizing apparatus the film of water flowing past the light varies with the type and size of the apparatus, from one-half inch to eight inches in depth.

ULTRA VIOLET RAY APPARATUS.—An ultra violet ray apparatus is simply a housing or casing with a transparent cylinder or tube inside which separates the light from the water. The water flows over and is in contact with this tube, while the light is inside of it safe from contact with the water. This transparent cylinder is made of quartz, ice and quartz being the only known solid substances which will permit the ultra violet rays to pass through them. A glass cylinder in this place would prevent sterilization, for the ultra violet rays would not pass through the glass.

The quartz tube is made water tight by stuffing boxes packed with rubber and protected by aluminum heat rings.

The water flows over this quartz cylinder and is thus exposed to the light from the lamp within the cylinder. The space between the apparatus housing and the outside of the quartz cylinder varies from one-half inch to eight inches, or if deeper, baffle plates are provided to stir the water and turn it over during its passage, and narrow the passage so water cannot flow through without having been exposed to the light in a comparatively thin stream.

The rays are produced in an ultra violet ray apparatus by a mercury vapor lamp—a mercury vapor arc in a vacuum. The lamp consists of a straight quartz tube with a bowl at one end, like a clay pipe. This tube is partially filled with mercury. Mercury is an electric conductor. When, therefore, two ends of the lamp are connected in an electric circuit, electricity flows through the mercury, but without producing any ultra violet rays. To form the mercury vapor arc the mercury bridge must be broken. This is done by raising the stem of the lamp slightly, either automatically or by hand. A short mercury vapor arc is then produced, just as the electric spark spans the distance between the carbon in an arc light. The pressure of the mercury vapor gradually forces the mercury up in the bowl, until in a few minutes no mercury is left in the stem. The mercury vapor arc then extends the full length of the tube, and ultra violet rays of great intensity are produced.

The mercury lamp is placed inside of the quartz cylinder in the ultra violet ray apparatus, and is fitted up to tip automatically once the current is turned on.

The ultra violet rays have no perceptible effect on the water treated, other than their germicidal action. The treatment does not change the temperature, taste, appearance, chemical or mineral properties. It does not charge with carbon dioxide, nor does it make the water "flat."

For sterilization by means of ultra violet rays the water must be clear and free from suspended matter. If it is not, a bacterium might get behind or inside a suspended particle and escape exposure to the rays. If, therefore, the water is not clear, it must be filtered before sterilization. Simple filtration without coagulation may then be resorted

to, the ultra violet rays affecting sterilization without adding an objectionable sulphate of iron or sulphate of alumina to the water.

While water must be free from suspended matter and turbidity for successful treatment with ultra violet rays, a certain amount of color and turbidity are permissible, so long as the color is not a deep one, or the turbidity over fifteen parts per million.

The "dosage" of application of the ultra violet rays is independent of the mineral or organic content of the water, and since no physical or chemical change is produced in the water by the ultra violet rays, a very heavy over-dosage beyond that theoretically required can be used, thereby giving full protection against unusual conditions which arise in most public water supplies.

Ultra violet ray apparatus are made in three types—portable, gravity and pressure. The pressure type is connected to the water supply system and the water flows through the apparatus under pressure. The gravity is an open type sterilizer through which the water flows by gravity under a very slight head.

CHAPTER XXVI

PREVENTION OF RUSTING IN WATER PIPES AND TANKS

The treatment of water to prevent it rusting pipes is not, strictly speaking, a purification process, nor is it, like filtration and ultra violet ray sterilization, a sanitary precaution. It is purely an economic measure, like water softening, intended to prevent pecuniary loss.

There are two methods of rust prevention, known respectively as *De-Aerating* and as *Deoxidizing* or *Deactivating*. The two methods are wholly unlike each other, although they achieve the same result, the prevention of rusting or pitting of iron or steel water pipes and tanks. Neither system is applicable to steam or other piping systems. They are used exclusively for water supply systems in buildings.

Rust prevention is affected by removing the air or oxygen from the water before it reaches the distributing system. Air, while not an element of water, is a natural constituent of it. At atmospheric pressure and ordinary temperature, water will absorb four per cent. of its own volume of air. By increasing the pressure of water, its capacity for absorption is increased in direct proportion. That is, if the pressure be increased to two atmospheres, the temperature remaining unchanged, pure water will absorb eight per cent. of its volume of air. Under a head of 100 feet, a moderate pressure in water supplies, water will absorb twelve per cent. of its volume of air. Without the air that is dissolved in all natural waters, fish and other aquatic animals could not live, and all water vegetation would die. Without wind to create waves and ripples, the air would soon become exhausted from ponds and lakes. In like manner, without air in the water supplied to buildings, the pipes would not rust, nor would iron of any kind rust in water from which all air was expelled. It is well

known to chemists that corrosion is directly proportional to the amount of free oxygen dissolved in water.

While water under compression can absorb four per cent. of air for each atmosphere of pressure, it seldom contains more than four per cent., as that is the point of saturation at atmospheric pressure, which is the pressure at which it is taken into the system. The air is made up of .21 per cent. by volume of oxygen; .78 per cent. nitrogen, and .01 per cent. argon. It is the oxygen in the air that causes the corrosion, and with four per cent. of air in water the oxygen content would be .84 per cent., or almost one per cent.

Water and iron alone do not produce rust. Iron and air alone cannot produce rust. What is needed is iron, air and water. Take away any one of these three essentials, and rust will be prevented. The iron or the water cannot be taken away in a water supply system, so in both deactivating and de-aerating the air—or dissolved oxygen—is removed.

Rust occupies about ten times the volume of the iron which produced it. This accounts for small pipes being so badly choked they materially reduce the supply of water, particularly in the upper stories of buildings.

The formation of rust is greater in the hot water system than in the cold water pipes. This is probably due to the fact that heating water lessens its absorption in direct proportion to the amount of heat applied. The relative volume of air absorbed is in all cases directly as the pressure, and inversely as the temperature. Thus, as has already been stated, if the pressure be increased it will absorb more air, and if it be heated it will absorb correspondingly less air.

The air or oxygen liberated by heat in the hot water system is free to attack the pipes. That is why there is so much more trouble from hot water pipes pitting than from cold water pipes, and that is why rust prevention is applied generally to the hot water system and seldom to the cold, although the treatment is equally applicable to any water, hot, cold, fresh or salt.

DEACTIVATING OR DEOXIDIZING APPARATUS.—In the deactivating method of rust prevention, the apparatus is located in the basement or cellar near the heater, and water flows from the heater to the deactivating tank, while all its dissolved oxygen is liberated from the water and is ready to unite with anything suitable for which it has an affinity. The deactivating tank is partially filled with iron strips which the water attacks, producing all the rust of which it is capable under the circumstances. If it did not expend its energy there, it would attack and pit the pipes. The tank is easily cleaned and charged with deactivating material whenever necessary.

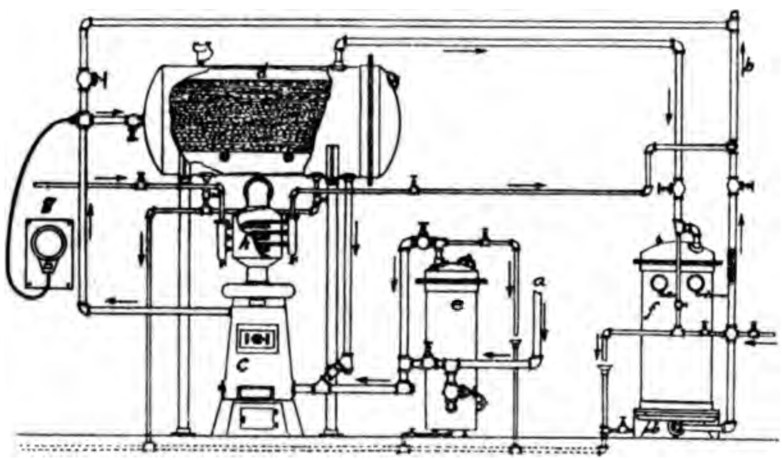


Fig. 116
Deactivating Apparatus

A deactivating system in which coal is used for fuel is shown in Fig. 116. From the coal heater, *c*, the heated water flows in the direction of the arrows to the deactivator, *d*, then to the filter, *f*, with a by-pass direct to the building. When the hot water leaves the deactivating tank it contains rust. This rust is removed by the filter so that when the water enters the distributing system it is clean and practically freed from oxygen.

Water enters the system through the pipe *a*, passes through or by-passes around the coagulate tank, *e*, as the

case may be, into the heater. The circulation pipe returns, as shown by the arrows, over the recording thermometer, *g*, and flows through the re-heater, *h*, then back to the house supply, *b*, again.

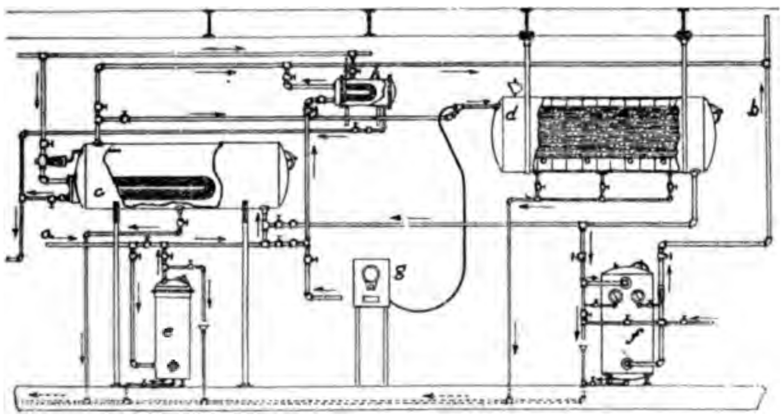


Fig. 117
Deactivating Apparatus

In Fig. 117 is shown the same system in which steam coils take the place of the coal heater. Cold water enters through pipe, *a*, passing through or by-passing the coagulate tank, *e*, to the heater, *c*, which is provided with a steam coil. From the steam coil it passes to the deactivator, *d*, which is by-passed as in the preceding illustration. From the deactivator it flows to the filter to remove the rust, then out through *b* to the hot water distributing system. The tank, *h*, is a steam heated re-circulation heater to boost the temperature of the water in the circulation pipe from the building, so it can again mingle with the house supply without passing through the deactivator again.

DE-AERATING APPARATUS.—The de-aerating process of rust prevention is based on the fact that very hot water cannot hold air in solution. It is assisted by the further fact that reducing the pressure, even of cold water, reduces the amount of air it can hold in solution. In de-activation the water is almost boiled in an open type of apparatus on the roof of a building, or above the highest outlet in the

system. The treated water then flows direct to the hot water heater in the basement, thence to the hot water distributing system. The deactivating apparatus can be located in the basement or sub-basement of a tall building, but its operation is not so satisfactory as when at the top of the building. Heating the water in open tanks at the top of the building removes about ninety per cent. of the dissolved

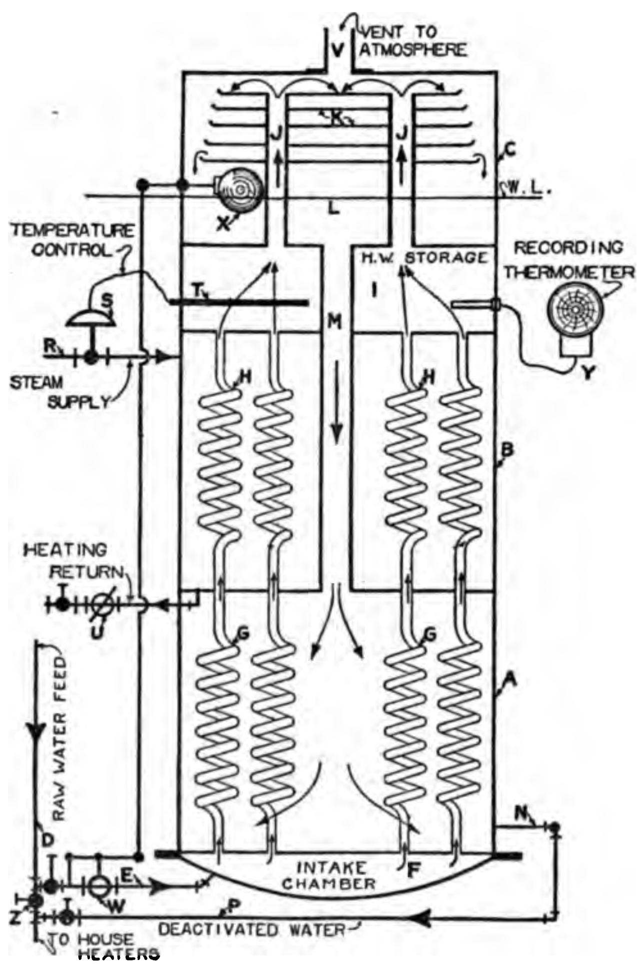


Fig. 118
De aerating Apparatus

oxygen. This reduces the corrosion to about one-tenth of the rate that would obtain with raw untreated water, giving to hot-water pipes a prolonged life with a ratio of about one to ten.

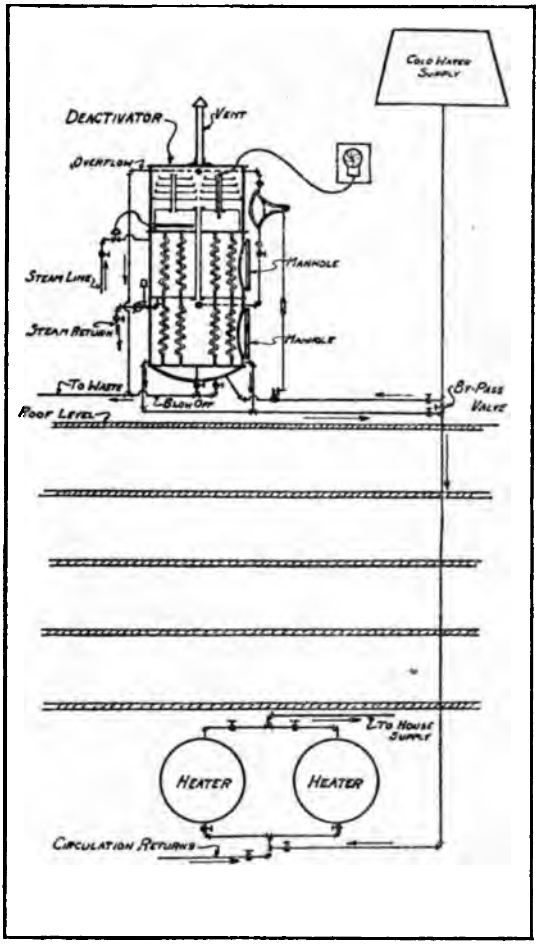


Fig. 119
Method of Installing De-aerator

A deaerating apparatus is shown diagramatically in Fig. 118. Cold water enters the intake chamber, *f*, flows up through the spiral coils, *g*, through the lower part of the tank, where the treated water is stored ready to be drawn. In the storage compartment the incoming water absorbs some of the heat from the treated water, thereby preparing it for the next stage in the coils, *h*. These coils are surrounded by steam, and the water is raised to a temperature of 207 degrees Fahrenheit, at which temperature it readily parts with the dissolved oxygen, which is liberated as the water falls over the baffle plates, *k*, into the funnel, *l*, and through the duct, *m*, to the storage or exchange chamber.

The temperature of the water in the coils, *h*, is regulated by the automatic temperature control, *s*. It parts with some of its heat, as before explained, to the water in the coils, *g*, and reaches the water heater in the cellar at a temperature of about 120 degrees Fahrenheit.

The diagram, Fig. 119, shows the way a de-aerating apparatus is installed in a building with relation to the other parts of the water supply system.

PART IV
HOT WATER SUPPLY

CHAPTER XXVII
WATER HEATING APPARATUS

Properties of Heat

TRANSFER OF HEAT.—When two bodies of different temperatures are near each other a transfer of heat takes place from the hotter to the colder body. This tendency towards maintaining an equilibrium of temperature is universal and the transfer of heat may take place in any of three ways; by *conduction* by *convection* or by *radiation.*

Conduction is the progressive movement of heat through a substance without perceptible movement of the molecules; if one end of a poker be held in a fire, the other

TABLE LX. Absorption and Radiation of Heat

Substance	Powers	
	Radiating or Absorbing	Reflecting
Lampblack	100	0
Water	100	0
Carbonate of lead	100	0
Writing paper	98	2
Marble	93 to 98	7 to 2
Isinglass	91	9
Ordinary glass	90	10
Ice	85	15
Cast iron	25	75
Wrought iron, polished	23	77
Steel, polished	17	83
Tin	15	85
Brass, cast, dead polished	11	89
Brass, hammered, dead polished	9	91
Brass, cast, bright polished	7	93
Brass, hammered, bright polished	7	93
Copper, varnished	14	86
Copper deposited on iron	7	93
Copper, hammered or cast	7	93

end will become heated by conduction. Water in a waterback or vessel becomes heated from the flames and hot gases of a fire by conduction of heat through the metal walls of the waterback or vessel.

Convection is the transfer of heat by movement or circulation of the molecules of the substance to be heated. Water in a vessel placed on a stove is heated by local circulation of the water. Fluids and gases, such as water or air, can be heated only by convection. This is due to the fact that when heat is applied to a fluid, the particles in contact with the heat expand in bulk, consequently become lighter in weight and are replaced by colder and denser particles.

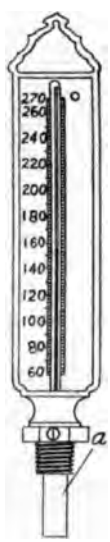


Fig. 120
Thermometer for Indicating Water Temperatures

Radiation is the transmission of heat through space from a warm body to one of lower temperature. For example, the Earth is warmed by radiation from the Sun. Radiant heat does not heat the air through which it passes; it travels direct and in straight lines until intercepted, when it is reflected or absorbed by this interceptive body. The cooler body will reflect or absorb or partly reflect and partly absorb all the heat rays it intercepts and the sum of the absorption and reflection equals the total of the intercepted rays.

Absorption and radiation are equal and opposite. The better the absorptive power of a substance the better radiating material it would make. Lampblack, which has absorbing and radiating powers rated at 100, is taken as the standard of comparison. In proportion as the reflecting power of a substance diminishes, its power to absorb or radiate heat increases. The absorbing, radiating and reflecting capacity of various substances are given in Table LX.

MEASUREMENT OF HEAT.—The amount of heat transmitted to water is measured by the *British Thermal Unit* usually abbreviated B. T. U. A B. T. U. is the quantity of heat required to raise the temperature of one pound of water

from 62 to 63 degrees Fahrenheit. In practice it is taken as the quantity of heat required to raise one pound of water 1 degree Fahrenheit.

MEASUREMENT OF TEMPERATURE.—The temperature of water is measured by a mercury thermometer. For measuring water temperatures, thermometers, Fig. 120, should have a scale ranging from 60 degrees Fahrenheit to 270 degrees Fahrenheit, and should be so constructed that when screwed into a fitting the mercury bulb, *a*, will project into the pipe and thus be in contact with the hot water.

TRANSMISSION OF HEAT.—The quantity of heat transmitted to water through a vessel or tube depends on the difference in temperature between the heating medium and the absorbing water, the thickness of the walls of the vessel or tube, and the material of which it is made. All other conditions being equal, copper pipes will transmit 50 per cent. more heat than iron pipes, and cast iron surfaces will transmit about 60 per cent. less than an equal area of iron

TABLE LXI. Transmission of Heat

Experimenters	Character of Surface	Steam condensed per square foot per degree difference of temperature per hour		Heat transmitted per square foot per degree difference of temperature per hour		Remarks
		Heating Pounds	Evaporating Pounds	Heating B.T.U.	Evaporating B.T.U.	
Laurens	Copper coils	.292	.981	315	974	
Laurens	2 Copper coils	....	1.20	....	1120	
Laurens	Copper coil	.268	1.26	280	1200	
Perkins	Iron coil	....	.24	....	215	100 lbs. Pressure
Perkins	Iron coil	....	.22	....	208.2	10 lbs. Pressure
Box	Iron tube	.235	....	230	...	
Box	Iron tube	.196	....	230	...	
Box	Iron tube	.206	....	207	...	
Havrez	Cast iron boiler	.077	.105	82	100	

Kent's Pocketbook.

pipe surface. The relative transmission of heat for different metals is shown in Table LXI.

From the above table of experiments, Table LXII of average heat units transmitted through various substances is adduced. The table is based on the assumption that the outer surface is clean and free from soot or ashes, and that the inner surface is free from incrustations of lime or other substances.

TABLE LXII. Comparison of Different Heat Transmitting Surfaces

Materials	Heat transmitted per square foot of heating surface each hour for each degree Fahr. difference between the heating medium and the water
Copper plate	275 B. T. U.
Copper pipe	300 B. T. U.
Wrought iron or steel pipe or surface	200 B. T. U.
Cast iron surface	80 B. T. U.

TEMPERATURE OF FIRES.—Temperature tests of a fire by observation can be told in a fairly exact manner by Table LXIII.

TABLE LXIII. Temperature of Fires

Appearance of Fire	Approximate Temperature, Fahr.
Red, just visible	About 977 degrees
Red, dull	About 1290 degrees
Dull red, cherry	About 1470 degrees
Red, full cherry	About 1650 degrees
Red, bright	About 1830 degrees
Orange, dull	About 2010 degrees
Orange, bright	About 2190 degrees
White heat	About 2370 degrees
White, welding	About 2550 degrees
White, dazzling	About 2730 degrees

Properties of Hot Water

EXPANSION OF WATER.—When water at or above the temperature of 39.1 degrees Fahrenheit is heated it expands in volume. The temperature 39.1 degrees Fahrenheit is known as the point of *maximum density*. When the water

is at a lower temperature the application of heat causes it to contract in bulk and the application of cold causes it to expand.

The expansion, weight, density and comparative volume of pure water at different temperatures can be found in Table LXIV.

The increase in bulk of a given quantity of water can be found by the formula:

$v = \frac{oc}{q}$, in which v = final volume of water, o = original volume of water, c = comparative volume of water at final temperature, q = comparative volume of water at original temperature.

EXAMPLE—What will be the final volume in a vessel containing 40 gallons of water at 62 degrees Fahr. when raised to a temperature of 200 degrees Fahr.?

SOLUTION—In Table LXIV it will be seen that the comparative volume of water at 62 degrees Fahr. is 1.00101 and at 200 degrees Fahr. 1.03889. Substituting those values in the formula,

$$V = \frac{40 \times 1.03889}{1.00101} = 41.51 \text{ gallons final volume.—Answer.}$$

The contraction in bulk of a given quantity of water can be found by the formula, $V = \frac{oc}{q}$ as in the former case, with this difference, however, that the original temperature and volume in this case is the higher one, while the final temperature and volume is the smaller one.

EXAMPLE—What will be the final volume of 41.514 gallons of water that is cooled from 200 degrees Fahr. to 62 degrees Fahr.?

SOLUTION—$\frac{41.514 \times 1.00101}{1.03889} = 40$ gallons.—Answer.

BOILING POINT OF WATER.—The temperature at which water boils varies with the pressure. In a vacuum of 13.69 pounds below atmospheric pressure water boils at a temperature of 102.018 degrees Fahrenheit. At atmospheric pressure, which is generally taken as 14.7 pounds per square inch, water boils at 212 degrees Fahrenheit. At 15.31 pounds pressure above atmospheric pressure water boils at a temperature of 250.293 degrees Fahrenheit. The

TABLE LXIV. Volume and Density of Water at Different Temperatures

CALCULATED BY MEANS OF RANKIN'S APPROXIMATE FORMULA

(D. K. CLARK)

Temperature	Comparative Volume	Comparative Density	Weight of 1 cubic foot	Remarkable Temperatures
Degrees Fahr.	Water at 32° = 1	Water at 32° = 1	Pounds	
32	1.00000	1.00000	62.418	Freezing Point.
35	0.99993	1.00007	62.422	
39.1	0.99989	1.00011	62.425	Point of maximum density.
40	0.99989	1.00011	62.425	
45	0.99993	1.00007	62.422	
46	1.00000	1.00000	62.418	Same volume and density as at the freezing point.
50	1.00015	0.99985	62.409	
52.3	1.00029	0.99971	62.400	Weight taken for ordinary calculations.
55	1.00038	0.99961	62.394	
60	1.00074	0.99926	62.372	
62	1.00101	0.99899	62.355	Mean temperature.
65	1.00119	0.99881	62.344	
70	1.00160	0.99832	62.313	Cold baths.
75	1.00239	0.99771	62.275	
80	1.00299	0.99702	62.240	
85	1.00379	0.99622	62.182	Tepid baths.
90	1.00459	0.99543	62.133	
95	1.00554	0.99449	62.074	Warm baths.
100	1.00639	0.92365	62.022	Temperature of condenser water
105	1.00739	0.99260	61.960	Hot baths.
110	1.00889	0.99119	61.868	
115	1.00989	0.99021	61.807	
120	1.01139	0.98874	61.715	
125	1.01239	0.98808	61.654	
130	1.01390	0.98630	61.563	
135	1.01539	0.98484	61.472	
140	1.01690	0.98339	61.381	
145	1.01839	0.98194	61.291	

Temperature	Comparative Volume	Comparative Density	Weight of 1 cubic foot	Remarkable Temperatures
Degrees Fahr.	Water at 32° = 1	Water at 32° = 1	Pounds	
150	1.01889	0.98050	61.201	
155	1.02164	0.97882	61.096	
160	1.02340	0.97714	60.991	
165	1.02589	0.97477	60.843	
170	1.02690	0.97380	60.783	
175	1.02906	0.97193	60.665	
180	1.03100	0.97006	60.548	
185	1.03300	0.96828	60.430	
190	1.03500	0.96632	60.314	
195	1.03700	0.96440	60.198	
200	1.03889	0.96256	60.081	
205	1.0414	0.9602	59.93	
210	1.0434	0.9584	59.82	
212	1.0444	0.9575	59.76	Boiling point by formula.
212	1.0466	0.9555	59.64	Boiling point by direct measurement.
230	1.0529	0.9499	59.26	
250	1.0628	0.9411	58.75	
270	1.0727	0.9323	58.18	
290	1.0838	0.9227	57.59	
298	1.0899	0.9175	57.27	Temperature of steam of 50 lbs. effective pressure per square inch.
338	1.1118	0.8994	56.14	Temperature of steam of 100 lbs. pressure per square inch
366	1.1301	0.8850	55.29	Temperature of steam of 150 lbs. pressure per square inch
390	1.1444	0.8738	54.54	Temperature of steam of 205 lbs. effective pressure per square inch.

relation between the boiling temperature of water and the pressure is absolute; pressure cannot be increased without also increasing the temperature of the boiling point of the water, nor can the temperature of the boiling point of the water be increased without increasing the pressure. The temperature and pressure of boiling water and the tempera-

TABLE LXV. Boiling Point of Water

Absolute Pressure in pounds per square inch.	Boiling point of water, degrees Fahrenheit.	Ratio of volume of steam to volume of equal weight of distilled water at temperature of maximum density.	Absolute Pressure in pounds per square inch.	Boiling point of water, degrees Fahrenheit.	Ratio of volume of steam to volume of equal weight of distilled water at temperature of maximum density.
1	2	3	1	2	3
1	102.018	20623	46	275.704	563.0
2	126.302	10730	48	278.348	540.9
3	141.654	7325	50	280.904	520.5
4	153.122	5588	52	283.381	501.7
5	162.370	4530	54	285.781	484.2
6	170.173	3816	56	288.111	467.9
7	176.945	3302	58	290.374	452.7
8	182.952	2912	60	292.575	438.5
9	188.357	2607	62	294.717	425.2
10	193.284	2361	64	296.805	412.6
11	197.814	2159	66	298.842	400.8
12	202.012	1990	68	300.831	389.8
13	205.929	1845	70	302.774	379.3
14	205.604	1721	72	304.669	369.4
14.69	212.000	1646	74	306.526	360.0
15	213.067	1614	76	308.344	351.1
16	216.347	1519	78	310.123	342.6
17	219.452	1434	80	311.866	334.5
18	222.424	1359	82	313.576	326.8
19	225.255	1292	84	315.250	319.5
20	227.964	1231	86	316.893	312.5
22	233.069	1126	88	318.510	305.8
24	237.803	1038	90	320.094	299.4
26	242.225	962.3	92	321.653	293.2
28	246.376	897.6	94	323.183	287.3
30	250.293	841.3	96	324.688	281.7
32	254.002	791.8	98	326.169	276.3
34	257.523	748.0	100	327.025	271.1
36	260.833	708.8	105	331.169	258.9
38	264.093	673.7	110	334.582	247.8
40	267.168	642.0	115	337.874	237.6
42	270.122	613.3	120	341.058	228.3
44	272.965	587.0			

ture and pressure of the steam in contact with it are always equal.

The relative pressure and temperature of boiling water and steam, also the volume of steam at that pressure compared to the volume of water of which it is composed can be found in Table LXV.

CIRCULATION OF WATER.—Water is a poor conductor of heat. It cannot be heated by conduction or by radiation. If heat is applied to the top of a vessel of water, but slight rise of temperature will result. Water must be heated by circulation or convection, and to cause the water to circulate the heat must be applied at the lowest part of the containing vessel.

If heat is applied to the bottom of a vessel of water, the water immediately begins to circulate. The water directly above where the heat is applied is heated by conduction, expands in bulk, consequently becomes lighter. It is then displaced by the cooler and denser water surrounding it, which in turn becomes heated and is displaced by the surrounding water; thus establishing local circulation of the water inside of the vessel.

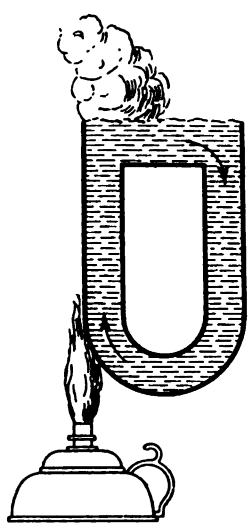


Fig. 121
Circulation of Water

If in place of a vessel of water a U-shaped tube, Fig. 121, be used and the ends of the loop connected at the top, as shown in the illustration, the water will rise in the leg of the tube to which the heat is applied, and will descend in the other leg to replace the ascending column of water. This establishes a continuous movement of the entire volume of water in the tubes in the direction of the arrows. This movement is known as circulation in a circuit. That is what occurs when water in a storage tank or range boiler is heated from a waterback or water heater.

The velocity of circulation in a circuit depends upon the temperature to which the water is heated and the height

of the circuit. Thus with a hot fire and a high loop the velocity of flow would be much greater than with the same loop and a slow fire or with a hot fire and a low loop. The chief cause retarding circulation is friction, therefore short radius bends, contracted waterways, small pipes and unreamed pipe ends should be avoided when installing hot water supply systems.

MIXING WATERS OF DIFFERENT TEMPERATURES.—The resulting temperature when two or more quantities of water of different temperatures are mixed, can be found by dividing the total number of heat units by the weight of water. Instead of reducing the water to pounds weight, however, the method can be shortened as shown by the following example and solution.

EXAMPLE—What will be the temperature resulting from mixing 30 gallons of water at 50 degrees Fahrenheit, with 15 gallons of water at 180 degrees temperature?

SOLUTION—30 gals. of water at 50° equals 30 $\times$ 50 or 1500
15 gals. of water at 180° equals 15 $\times$ 180 or 2700

45 4200

4200 divided by 45 gives 93 plus, which would be the temperature of the water after mixture.

Three, five, ten or any number of quantities may be mixed the same way, and the resulting temperatures determined by dividing the total quantity of heat found by adding the products of the several volumes times their temperatures, by the total number of gallons in the mixture.

RULE II—To find the amount and temperature of water required, to result in a mixture of given volume and temperature, the cold or hot water volume and temperature being known: Multiply the total gallons of the required mixture by the required resultant temperature to find the total degree-gallon requirement; subtract from that product the product of the known number of gallons and the known temperature, which product is the known degree-gallon factor. From the total gallons required subtract the total gallons of the known factor to find the amount of water necessary to give the required volume. Divide that remainder

into the difference between the total degree-gallon requirement and the known degree-gallon factor. The quotient will be the temperature at which the required volume must be to give the resultant temperature required.

EXAMPLE—How much water and at what temperature must be added to 15 gallons of water at 50° to give 30 gallons of water at 110°?

SOLUTION—30 gals. × 110° (required resultant) = 3,300 degree-gallons. 15 gals. × 50° = 750 degree-gallons. (The known degree-gallon factor.) 3,300 — 750 = 2,550 (The required degree-gallon factor.) 30 gals. — 15 gals. = 15 gals. (Required volume.) 15) 2550 (170° = Answer = 15 gallons of water at 170° will, when added to 15 gallons of water at 50°, result in 30 gallons of water at 110°.

EXAMPLE—How much water and at what temperature must be added to 20 gallons of water at 140° to result in a volume of 45 gallons at 100°?

SOLUTION—45 gals. × 100° = 4,500 degree-gallons. 20 gals. × 140° = 2,800 degree-gallons. 4,500 — 2,800 = 1,700 degree-gallons. 45 gals. — 20 gals. = 25 gals. 25) 1700 (68° = Answer = 25 gallons of water at 68° added to 20 gallons of water at 140° will result in a volume of 45 gallons of water at 100°.

WATERBACKS.—The hollow casting forming part of the fire-box lining of kitchen ranges, and through which water circulates and is heated for storage in the range boiler, is commonly known as a waterback. In most waterbacks a horizontal partition, *a*, Fig. 122, gives the water a positive circulation through the casting and prevents a commingling of waters of different temperatures, as is the case where waterbacks without this partition are used. It is quite important that the opening for the flow pipe, *b*, be drilled close to the top wall of the casting, so that the hottest water can flow from the waterback and not cause a rattling sound by being retained in the waterback to form steam.

WATER HEATING COILS.—In ranges which are not provided with waterbacks, heating coils are sometimes made to supply the deficiency. Usually they consist of two pieces of one-inch black iron pipe joined at one end by a return bend. The free ends are then extended through the wall of the fire-box, so they can be connected to the boiler. The chief objection to the use of water heating coils is the fact that their effect on the draft of the stove or on the heating

capacity of the oven can never be pre-determined, consequently ovens are often spoiled for baking purposes by placing a water coil in a range not designed to accommodate one.

CAPACITY OF WATERBACKS AND COILS.—The capacity of waterbacks and coils depends upon the materials of which they are made, the thickness of metal forming their walls, the location of the waterback or coil in the fireplace, their freedom from soot, ashes or incrustation of lime or magnesia, and the intensity of the fire to which they are exposed. Under favorable conditions a coil made of copper pipe will transmit 300 B. T. U. per hour, a wrought iron or steel pipe, 200 B. T. U. per hour, a cast iron waterback, 80 B. T. U. per hour per square foot, for each degree Fahrenheit difference in temperature between the flames or hot gases in contact with the waterback or coil and the water inside. As a matter of fact, however, waterbacks and coils transmit only about 25 per cent. of their possible capacity. This is due to the fact that they are placed in the firebox in the position least likely to affect the stove for other purposes, and therefore are not exposed to the hottest coals and gases of the fire. Furthermore, they are partly covered by ashes, soot and dying coals, and in the case of cast iron waterbacks, the walls usually are of too great thickness to transmit the maximum amount of heat. In many cases waterbacks and coils are coated with incrustations of lime or magnesia that still further reduce their transmitting capacities. New or clear cast iron waterbacks, under ordinary conditions, will heat from ordinary temperature to 200 degrees Fahrenheit from 25 to 35 gallons of water per hour for each square foot of exposed surface. With an ordinary fire, one square foot of exposed waterback surface will heat about 25 gallons of water per hour, while with a fire such as

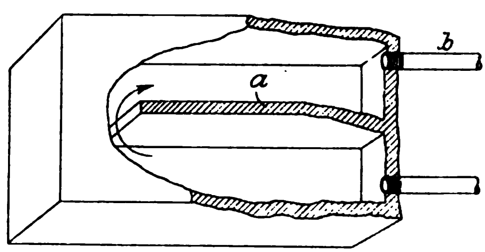


Fig. 122
Waterback

is used for baking or roasting, one square foot of surface will heat about 35 gallons of water per hour.

However, the average size of waterback contains only 110 square inches or about 2/3 square foot of exposed surface, and water for domestic uses is seldom heated to above the temperature of 180 degrees Fahrenheit, therefore an ordinary waterback with an average fire will heat from ordinary temperature to boiling point about 17 gallons of water per hour, or from ordinary temperature to 180 degrees Fahrenheit about 21 gallons of water per hour, while with a fire such as is used for cooking or baking it will heat 23 gallons of water to the boiling point, or 27 gallons of water to a temperature of 180 degrees Fahrenheit. Wrought iron pipes will heat from 30 to 40 gallons of water under the same conditions, and copper pipes will heat from 45 to 60 gallons per hour for each square foot of surface exposed to the fire. In calculating the heating capacity of a waterback or coil, the average temperature of the water is taken; thus, if water at 60 degrees Fahrenheit is heated to 200 degrees Fahrenheit, the average temperature of the water would be $60 + 200 \div 2 = 130$ degrees Fahrenheit, and the range of temperature through which it is heated would be $200 - 60 = 140$ degrees Fahrenheit.

Fig. 123
Water Heater

WATER HEATERS.—A magazine feeding water heater, such as is used for heating large quantities of water in apartment houses, barber shops, bathing establishments, etc., is shown in section in Fig. 123. It consists simply of a combustion chamber surrounded by an annular space through which water circulates and is heated from the flames and hot gases within. Heaters of this type are made having capacities of from 50 to 600 gallons per hour, and larger sectional heaters of different types are made with

capacities up to several thousand gallons per hour. The heater shown in the illustration has a magazine feed. This consists simply of a tube in the center of the heater that holds several hours' supply of coal and automatically feeds it to the fire. It can be made into a hand-fired heater by removing the magazine. A magazine feed heater, however, is preferable to a hand feed heater for the reason that it will run for 24 hours if necessary without attention.

CAPACITY OF WATER HEATERS.—The capacity of a water heater depends upon the amount of coal it can efficiently burn during a given period of time, and the conductivity and thickness of the walls of the fire-box. Boiler iron is a better conductor of heat than cast iron, therefore a boiler iron heater of given surface will heat more water in an hour than will a cast iron heater of equal surface, the amount of coal burned and the intensity of the fire in both cases being equal. The amount of coal economically burned in a heater depends upon the area of grate and size of the smoke flue. Heaters burn from 3 to 6 pounds and will probably average 4 pounds of coal per hour per square foot of grate surface. The total heat of combustion of a pound of coal of average composition is 14.133 B. T. U. Of this amount, however, a large percentage passes up the chimney as hot gases, so that under ordinary conditions only about 8000 B. T. U. are actually transmitted to the water. Therefore, in calculating the capacity of a heater, the area of grate surface, amount of coal efficiently burned and the available B. T. U. in a pound of coal are the limiting factors. Architects and plumbers should determine for themselves, by calculation, the heating capacity of a heater, and not rely upon manufacturers' ratings. This is made necessary by the lack of uniformity among manufacturers in the rating of their heaters, which differ from one another in some cases over 100 per cent. for equal area of grates. Some part of that percentage might be accounted for by the difference of construction, which gives some heaters greater heating surface than others, but, making due allowance for the improved design of some heaters, they will invariably be found overrated, while the run of heaters are overrated

from 20 to 50 per cent. The capacity of heaters can be calculated by means of the rule or formulas following:

When the quantity of water to be heated per hour is known, the size of grate required can be found by the following rule:

Rule—Multiply the weight of water in pounds by the number of degrees rise in temperature and divide the product by the number of pounds of coal burned per hour per square foot of grate surface, by the number of heat units transmitted to the water from 1 pound of coal. The result will be the area in square feet of grate required.

Expressed as a formula:

$g = \frac{W\,t}{C\,u}$, in which W = weight in pounds of water to be heated, t = degrees Fahr. water is to be raised, C = pounds of coal burned per hour per square foot of grate, u = units of heat absorbed by water from each pound of coal, g = area of grate in feet.

EXAMPLE—What size of grate will be required to heat 300 gallons of water per hour from 62 to 212 degrees Fahr., 1 gallon weighing 8.3 pounds?

SOLUTION—$\frac{300 \times 8.3 \times (212\text{-}62)}{6 \times 8000} = 7.7$ sq. ft. grate surface.—**Answer.**

In the above solution 6 pounds of coal was assumed as the consumption per square foot of grate surface because the maximum rating of the heater is desired.

The capacity of a water heater of known dimensions can be ascertained by the following rule:

Rule—Multiply the consumption of coal per square foot of grate surface by the number of B. T. U. transmitted to the water from each pound of coal, by the number of square feet of surface in the grate, and divide the product by the weight of 1 gallon of water times the degrees of temperature the water is raised.

Expressed as a formula:

$q = \frac{g\,c\,u}{p\,t}$, in which g = size of grate in square feet, c = pounds of coal burned per hour per square foot of grate surface, u = units of heat absorbed by the water from each pound of coal, p = 8.3 weight of 1 pound of water, t = degrees Fahr. water is raised, q = quantity of water in gallons heated per hour.

EXAMPLE—How many gallons of water can be heated from 62 to 212 degrees Fahr. in a heater with 7.7 square feet of grate surface?

SOLUTION— $\frac{7.7 \times 6 \times 8000}{8.3 \times (212-62)} = 296.$— Answer.

In selecting a water heater, the time the heater must run on one charge of fuel must be taken into consideration. If a small heater were fired every half-hour with a light charge of coal, it would do as many such heaters are rated to do, furnish a certain specified amount of heat to the water. However, such a heater would be a nuisance, and would supply only part of the rated heat if fired only at long intervals, as heaters are supposed to be fired. A heater ought to hold enough coal to burn freely at the greatest rate of combustion it will have to in use, for at least four hours time. Assuming a combustion of six pounds of coal per hour for each square foot of grate surface, and a period of four hours the heater must run on one charge of fuel, then a space sufficient to hold $4 \times 6 = 24$ pounds of fuel would have to be provided in the combustion chamber for each square foot of grate surface. Anthracite coal weighs 95 pounds per cubic foot, so that a heater ought to have a storage capacity of one-quarter cubic foot for each square foot of grate surface. In addition to this storage capacity for coal the combustion chamber must have ample space for the burning of gases distilled from the coal, or the gases will escape without being burned, and the heating capacity will be greatly reduced. The gases cannot burn unless mixed with a large quantity of air, so it would be safe to say that at least one-half cubic

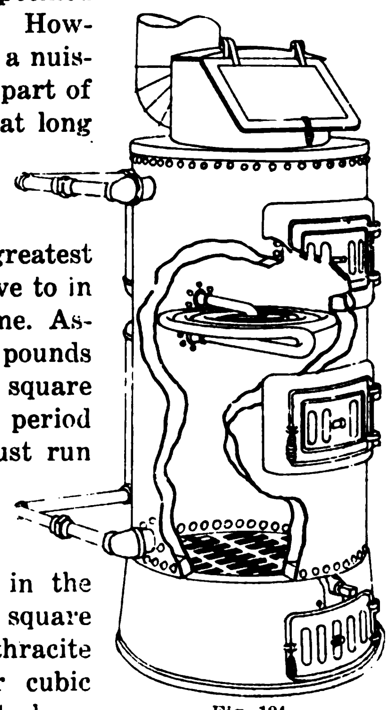


Fig. 124
Garbage Burning Water Heater

foot of space should be allowed in the fire box, in addition to the space occupied by the coal, for each square foot of grate surface.

GARBAGE BURNING WATER HEATERS.—Garbage burning water heaters are sometimes used in large institutions where they serve the double purpose of destroying refuse and heating water for domestic supply. A type of such water heater is shown in Fig. 124. Its distinguishing features are two grates, one an ordinary grate to burn coal or other fuel on, and the other a pipe coil through which water circulates and on which the garbage to be burned is placed. Where large quantities of combustible materials must be disposed of, such heaters are both efficient and economical.

SMOKE FLUES.—It is important that a good chimney flue, straight and smooth inside and proportioned to the area of the grate, be provided for each water heater. No other smoke pipe should be permitted to connect with this flue, nor should other openings to it be permitted, as they would spoil the chimney draft.

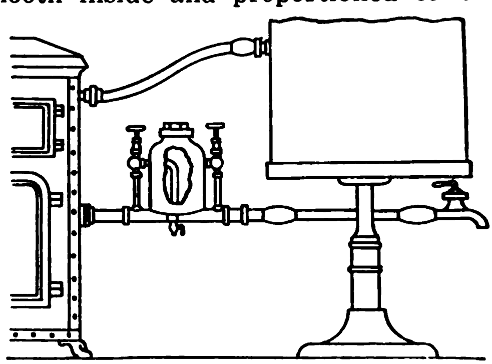


Fig. 125
Automatic Waterback Cleaner

Smoke flues should be cased with flue linings to give them a smooth interior surface. The best form for flue linings is round or oval, as smoke and hot gases pass up with less frictional resistance in a round flue than in a square one. Square flues are much more efficient than rectangular ones, on account of the less surface exposed for a given area of flue; for instance, a flue 12x12 inches has an area of 144 square inches and a perimeter of only 48 inches, while a flue 8x18 inches having an equal area, has a perimeter of 52 inches, thus presenting four additional inches to offer resistance. No satisfactory

formula was ever devised to calculate the area of smoke flues under varying conditions. A simple empirical rule that will be found satisfactory for determining the area of flues for water heaters follows:

Rule—Allow for smoke flue one-eighth the sectional area of heater grate.

EXAMPLE—What size of smoke flue will be required for a water heater containing 4 square feet of grate?

SOLUTION—4 square feet = 576 square inches. ⅛ of 576 = 72 square inches = area of smoke flue. The nearest sizes of commercial flue linings are: Square, 8½ × 8½ inches = 72.25 square inches round, 10^2 times .7584 = 78.54 square inches.

INCRUSTATION OF WATER HEATERS.—An apparatus for automatically feeding soda ash or other precipitating chemicals to hard water is shown in Fig. 125. This apparatus is used in connection with waterbacks and water heaters to prevent them becoming choked by deposits of lime. When properly looked after an apparatus of this kind will precipitate so large a quantity of the lime or magnesia held in solution by the waters, that the periods between cleanings of waterbacks or heaters will be lengthened from 50 to 100 per cent.

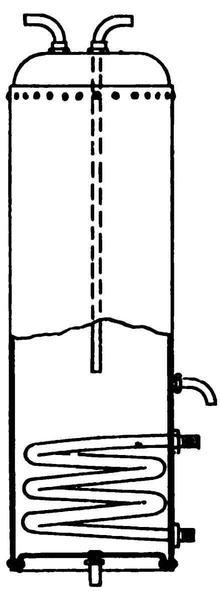


Fig. 126
Vertical Tank with Steam Coil

The precipitating reagents are placed in this vessel, wetted, and the two valves opened sufficiently to give a flow through the apparatus proportioned to the amount of water flowing through the pipe. The apparatus then works automatically until the chemical reagent is exhausted. To secure satisfactory results the apparatus must be placed on the return pipe to the waterback, as shown. All water is thus treated before reaching the waterback or heater.

STEAM COILS.—Water in tanks is sometimes heated by a steam coil immersed in the water. This method of heating has the advantage of requiring no care whatever, and saves the labor, expense and dirt of an extra fire. When exhaust steam is available the cost of heating water by this method is practically nothing.

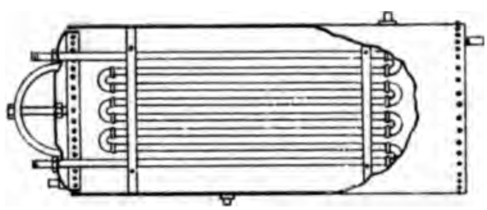


Fig. 127
Steam Coil in Horiontal Tank

A steam coil can be placed in either a vertical or in a horizontal tank, the only requirements being that the pipe used in the coil be large enough to take care of the water of condensation, and that it have a slight fall from the top connection where the steam enters to the bottom outlet towards which the water of condensation drains.

In a vertical tank, Fig. 126, the steam coil is spiral and placed near the bottom. This type of coil is used principally in connection with kitchen ranges. Large size hot water tanks are usually placed in a horizontal position. Fig. 127 shows a method of placing a coil for high pressure steam inside of a hot-water tank. In this coil, steam or the condensation, travels through the entire length of coil. When exhaust steam is used, however, a shorter course should be provided to minimize the back pressure on the engines. A heating coil for exhaust steam is shown in Fig. 128. This type of heater is better than a continuous coil, either for exhaust steam or for live steam.

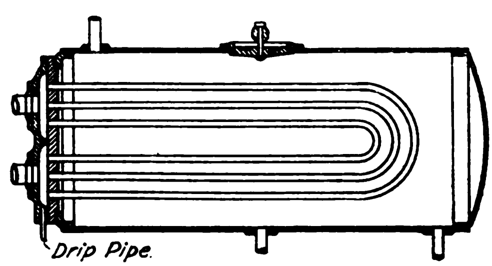


Fig. 128
Exhaust Steam Coil in Tank

Steam coils for tanks may be made of copper, brass

or iron pipe. Copper and brass pipes last longer than iron and transmit more heat to the water per square foot of heating surface. For these reasons, either copper or brass coils are preferable to iron pipe coils. The size of steam coil in square feet required to heat a certain quantity of water in a given time, can be found by the following rule:

Rule—Multiply the weight of water in pounds by the number of degrees temperature Fahrenheit the water is to be raised, and divide the product by the coefficient of transmission times the difference between the temperature of the steam and the average temperature of the water.

Expressed as a formula:

$s = \frac{w\,r}{c\,(T-t)}$, in which s = surface of copper or iron pipe in square feet, w = weight in pounds of water to be heated, r = rise in temperature of water, t = average temperature of the water in contact with coils, T = temperature of steam, c = coefficient of transmission.

The value of c for copper is 300 B. T. U. and for iron 200 B. T. U. transmitted per hour per square foot of surface for each degree difference between the temperature of the steam and the average temperature of water.

In computing the heating surface of copper or iron pipe in steam coils, the inner circumference of the pipe must be taken, as that is the real heating surface to which heat is applied. The average temperature of the water in contact with the coil is taken as the temperature of the water.

Example—How many square feet of heating surface will be required in a copper coil to heat 300 gallons of water per hour from 50 degrees to 200 degrees Fahr. with steam 15 pounds pressure?

Solution—$300 \times 8.3 = 2490$ pounds of water to be heated. $200° - 50° = 150°$ = rise in temperature of water. $150° \div 2 + 50° = 125°$ = average temperature of water. $250°$ = temperature of steam at 15 pounds gauge pressure (Table LXIX). $250° - 125°$ = difference between temperature of steam and average temperature of water. Substituting these values in the formula:

$$s = \frac{2490 \times 150}{300 \times (250-125)} = 9.9 \text{ square feet of coil. Answer.}$$

Some convenient constants for steam coils that produce approximations sufficiently accurate for most purposes follow. The values will be found safe:

$W =$ gallons water to heat per hour.
$W \div 10 =$ square feet iron pipe coil required for exhaust steam.
$W \div 15 =$ square feet copper coil required for exhaust steam.
$W \times .07 =$ square feet iron pipe coil for 5 pounds pressure steam.
$W \times .045 =$ square feet copper pipe coil for 5 pounds pressure steam.
$W \times .05 =$ square feet iron pipe coil for 25 pounds steam pressure.
$W \times .035 =$ square feet copper pipe coil for 25 pounds steam pressure.
$W \times .04 =$ square feet iron pipe coil for 50 pounds steam pressure.
$W \times .025 =$ square feet copper pipe coil for 50 pounds steam pressure.
$W \times .03 =$ square feet iron pipe coil for 75 pounds steam pressure.
$W \times .02 =$ square feet copper pipe coil for 75 pounds steam pressure.
$W \div 30 =$ horse-power of boiler to supply steam.
$W \div 7 =$ pounds of coal per hour to heat water.
$W \div 200 =$ tank heater grate area (not less 12 inches diam.).
$W \div 30 =$ square feet heating surface in tank heater.

Condensation from steam heating coil $= 1$ pound of steam per gallon of water heated per hour $= 1000$ heat units.

Increased weight or pounds of steam blown into water $=$ units of heat $\div 1000$.

Increase in gallons $=$ units of heat $\times 0.00012$.

The above data apply to closed tanks. For open kettles there is a large loss of heat by evaporation from the surface of the water. With a closed tank there is a loss of about 200 units per hour per square foot of exposed surface.

Taking the foregoing example for comparison, the nearest value to 15 pounds steam is 25 pounds, and the coefficient for copper pipe at this temperature is .035. Hence, $300 + .035 = 10.5$ square feet. Answer.

EXAMPLE—What size steam coil is required to heat 300 gallons per hour in a closed boiler with exhaust steam? $300 \div 10 = 30$ square feet in coil.

With steam at 25 pounds pressure? $300 \times 0.07 = 21$ square feet.

How many pounds of steam will be required? 300 pounds (1 pound per gallon).

What horse-power steam boiler will be required? $300 \div 30 = 10$ horse-power.

How many pounds of coal per hour? $300 \div 7 = 43$ pounds.

What size tank heater is required (grate area in square feet)? $300 \div 200 = 1\frac{1}{2}$ square feet $=$ about 17 inches diameter.

ACTUAL PERFORMANCE OF STEAM WATER HEATERS.—In the Union Central Office Building, Cincinnati, Ohio, are

three Goubert heaters for heating the water throughout the building. Hot water being used only at lavatories and slop sinks. Water enters the heater at a temperature of 72 degrees Fahrenheit, and the average temperature of the water delivered throughout the 30 stories of the building is 138 degrees F. There are in the building approximately 275 lavatories and slop sinks or fixtures supplying hot water to the tenants.

During the eight hours of the test it was estimated that 2494 pounds of steam were used in heating water for the building, or an average of 311.8 pounds per hour. The cost of producing hot water for eight hours was $0.2961, making the cost per hour $0.037. The cost of heating water per fixture per day averaged about $0.00108.

HEATING WATER BY STEAM IN CONTACT.—The quickest and most economical way to heat water with steam is to bring the steam into direct contact with the water. This method is used extensively to heat water in swimming pools, vats for industrial purposes, dish washing, etc., and is usually accomplished by forcing steam through a perforated pipe or steam nozzle located near the bottom of the tank and submerged by the water. When perforated pipes are used for this purpose they should be of brass or copper to prevent corrosion, and the combined area of the perforations should be at least eight times the area of pipe to equal it in capacity. Exhaust steam from pumps, engines or other apparatus, that is liable to contain oil or grease, is not suitable for this purpose.

When steam is brought in contact with water in an open vessel steam bubbles are formed, rise toward the surface and collapse with a report. For this reason water is heated by steam in direct contact through perforated pipes only when noise is not objectionable.

NOISELESS WATER HEATERS.—A steam nozzle for noiselessly heating water by steam in direct contact is shown in Fig. 129. This apparatus consists of an outward and upward discharging steam nozzle covered by a shield which has numerous openings for the admission of water, so that

the jet takes the form of an inverted cone, discharging upwards.

Air, admitted through a small pipe, is drawn in by the jet, and by mixing with the steam prevents the sudden collapse of bubbles and the consequent noise which is such a great objection to heating by direct steam in the old way. A valve or cock on this air pipe regulates the air to the quantity most desirable.

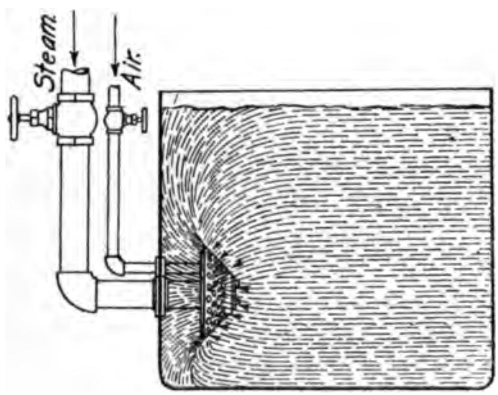


Fig. 129
Steam Water Heater

If water is to be heated to a less temperature than 165 degrees Fahrenheit, which would be the case in most installations, the air pipe is not used, as the heater will operate noiselessly without it. If, however, the temperature of the water is to be raised above 165 degrees Fahrenheit an air pipe must be used. A pressure of air is not required in the air pipe when the pressure of steam is sufficient to draw air in by inspiration. The pressure of steam required for this purpose is proportioned to the depth of water above the heater in the tank, and cannot be less than those given in Table LXVI.

TABLE LXVI. Pressures of Steam for Heads of Water

Head of water in feet above heater...	3	4	5	6	7	8	9	10
Minimum steam pressure, pounds....	4	8	12	18	24	32	40	50

If water is to be heated to a greater temperature than 165 degrees Fahrenheit with less steam pressure than is called for in the foregoing table, air must be supplied under pressure, and both the air pressure and the steam pressure

must equal in pounds the height in feet of water above the heater.

Stock sizes of this type of heater, with the manufacturers' ratings in B. T. U. per minute under different steam pressures, can be found in Table LXVII.

TABLE LXVII. Capacity of Noiseless Water Heaters

Diameter of Steam Pipe in Inches	Diameter of Air Pipe in Inches	Capacity in Heat Units (B. T. U.) per Minute Steam Pressure				
		10 Pounds	20 Pounds	40 Pounds	60 Pounds	80 Pounds
1/4	1/8	810	1,040	1,820	2,485	2,920
1/2	1/4	2,540	3,270	5,720	7,620	9,150
3/4	1/4	4,375	5,625	9,845	13,125	15,750
1	3/8	7,000	9,000	15,750	21,000	25,200
1½	1/2	17,500	22,500	39,300	52,500	73,000
2	3/4	26,700	34,300	60,100	80,000	96,000
2½	3/4	39,000	50,500	88,500	108,000	141,500
3	1	61,200	78,750	137,500	183,700	215,500
4	1¼	103,250	132,750	231,200	309,750	371,700
6	2	245,000	315,000	550,000	735,000	862,000

To find the size of heater required to heat a certain quantity of water in a given time, first find the number of B. T. U. required per minute and the pressure of steam and the size will be found in Table LXVII.

EXAMPLE—100 cubic feet of water shall be heated from 60 to 180 degrees, or 120 degrees increase, in 30 minutes, with steam of 80 lbs. pressure.

Weight of 1 cubic foot of water, 62.5 pounds.

$$\frac{62.5 \times 100 \times 120}{30} = \frac{750{,}000}{30} = 25{,}000 \text{ heat units per minute.}$$

Comparing this with table indicates the 1-inch steam pipe is the size required.

ANOTHER EXAMPLE—200 gallons of water shall be heated from 30 degrees to 90, or 60 degrees increase, in six minutes by steam of 10 pounds pressure. Weight of 1 gallon, 8.3 pounds.

$$\frac{8.3 \times 200 \times 60}{6} = \frac{99{,}600}{6} = 16{,}600 \text{ heat units per minute.}$$

Comparing this with the table indicates that 1½-inch steam pipe is the size required.

COMMINGLER.—An apparatus for noiselessly heating water by direct contact in a closed circuit is shown in Fig. 130. This apparatus is known as a *commingler*, and takes the place of, and is connected to, a storage tank in the same manner as a waterback or heater. Water from the hot water tank enters the commingler through the pipe *a*, passes up through the body of the casting and flows back through the pipe *b* into the tank. Steam is supplied to the heater through the pipe *c*, passes down pipe *d*, and escapes into the body of the commingler through the small holes, *e*, shown in the nozzle.

The admission of steam to the body of the water in this manner prevents the noise which is experienced when steam enters a body of cold water directly and without being previously broken up, as is done by these holes. Sometimes a portion of the interior of the casting is filled with small pebbles surrounding the nozzle, the effect being to still further break up the steam, which has to force its way through these pebbles before striking the main body of water in the casting.

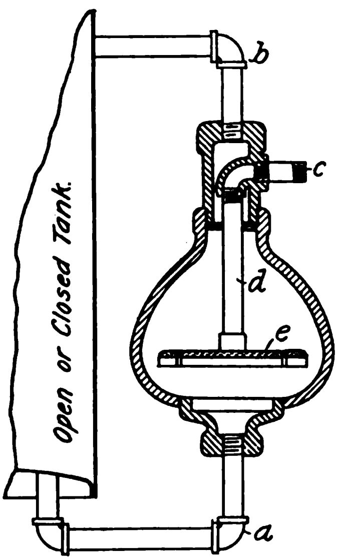


Fig. 130
Steam and Water Commingler

To use this apparatus in a closed circuit the steam pressure must be greater than the water pressure, and a check-valve should be placed in the steam pipe to prevent water flowing from the commingler to the steam boiler when the steam pressure is low.

HEAT TRANSMITTED BY STEAM TO WATER.—When steam is brought in contact with water of lower temperature than the steam, it almost instantly parts with all of its latent heat and all of its sensible heat above the temperature of the water. Thus, when a pound of steam is brought in

contact with water it imparts as many B. T. U. to the water as there are B. T. U. in a pound of steam at that pressure above the temperature of the water. For instance, there

TABLE LXVIII. B. T. U. in Water at Different Temperatures

Temperature, Degrees Fahr.	Number of B. T. U. reckoning from 0°	Number of B. T. U. Required to raise the Temperature of the Water to Boiling Point 212° Fahr.
35	35.000	177.900
40	40.001	172.899
45	45.002	167.898
50	50.003	162.897
55	55.006	157.894
60	60.009	152.891
65	65.014	147.886
70	70.020	142.880
75	75.027	137.873
80	80.036	132.864
85	85.045	127.855
90	90.055	122.845
95	95.067	117.833
100	100.080	112.820
105	105.095	107.815
110	110.110	102.790
115	115.129	97.771
120	120.149	92.751
125	125.169	87.731
130	130.192	82.708
135	135.217	77.683
140	140.245	72.655
145	145.275	67.625
150	150.305	62.585
155	155.339	57.561
160	160.374	52.526
165	165.413	47.487
170	170.453	42.447
175	175.497	37.403
180	180.542	32.358
185	185.591	27.309
190	190.643	22.257
195	195.697	17.203
200	200.753	12.147
205	205.813	7.087
210	210.874	2.016

are 1141.1 B. T. U. in one pound of steam at atmospheric pressure reckoning from the freezing point, and if allowed to expand in water with a temperature of 60 degrees Fahrenheit, the steam will part with all of its heat until the temperature of the water of condensation is equal to the temperature of the water to be heated. In doing so it will impart $1141.1 + 32 - 60 = 1113.1$ B. T. U. to the water, and will increase its bulk by one pound, or about $\frac{1}{8}$ gallon. The number of B. T. U. in a pound of steam varies with its temperature and pressure.

The number of B. T. U. contained in one pound of water at different temperatures, also the number of B. T. U. required to raise one pound of water from different temperatures to boiling point at atmospheric pressure, may be found in Table LXVIII.

STEAM REQUIRED TO HEAT WATER.—The weight of steam required to heat a given quantity of water from a certain temperature to boiling point can be found by the following rule:

Rule—Multiply the number of pounds of water to be heated by the number of degrees temperature the water is to be raised, and divide the product by the total heat of steam at the pressure it is to be used, less the sensible heat at atmospheric pressure.

This may be expressed by the formula:

$s = \frac{w\,h}{L - l}$ in which s = weight of steam in pounds, w = pounds of water to be heated, h = degrees Fahr. water to be heated; L = total heat of steam at pressure used, l = sensible heat at atmospheric pressure.

EXAMPLE—How many pounds of steam at 70 pounds pressure will be required to heat 7,500 pounds of water from 48 degrees Fahr. to boiling point?

SOLUTION—$\frac{7500\ (212-48)}{(1174-180)} = 1237$ pounds of steam. Answer.

An empirical rule that is sufficiently approximate for most purposes is to allow 1 pound of steam for 6 pounds of water to be heated. Taking the above example then:

$7500 \div 6 = 1250$ pounds of steam. Answer.

TABLE LXIX. Properties of Saturated Steam.

Absolute Pressure	Temperature Degrees Fahr.	Heat Units above 32 Degrees Fahr. Contained in 1 Pound of Steam			Weight of 1 Cubic Foot in Pounds	Volume of 1 Pound in Cubic Feet
		In Water	Latent Heat	Total Heat		
14.7	212.0	180.9	965.7	1146.6	.0379	26.37
15	213.1	181.6	965.3	1146.9	.0387	25.85
16	216.3	184.9	963.0	1147.9	.0411	24.33
17	219.5	188.1	960.8	1148.9	.0435	22.98
18	222.4	191.1	958.7	1149.8	.0459	21.78
19	225.3	193.9	956.7	1150.6	.0483	20.70
20	228.0	196.7	954.8	1151.5	.0507	19.73
21	230.6	199.3	953.0	1152.3	.0531	18.84
22	233.1	201.8	951.2	1153.0	.0554	18.04
23	235.5	204.3	949.5	1153.8	.0578	17.30
24	237.8	206.6	947.9	1154.5	.0602	16.62
25	240.1	208.9	946.3	1155.2	.0625	16.00
26	242.2	211.1	944.7	1155.8	.0649	15.42
27	244.3	213.2	943.3	1156.5	.0672	14.88
28	246.4	215.3	941.8	1157.1	.0695	14.38
29	248.4	217.3	940.4	1157.7	.0719	13.91
30	250.3	219.3	939.0	1158.3	.0742	13.48
31	252.2	221.2	937.7	1158.9	.0765	13.07
32	254.0	223.0	936.4	1159.4	.0788	12.68
33	255.8	224.8	935.1	1159.9	.0812	12.32
34	257.5	226.6	933.9	1160.5	.0835	11.98
35	259.2	228.3	932.7	1161.0	.0858	11.66
36	260.9	230.0	931.5	1161.5	.0881	11.36
37	262.5	231.6	930.4	1162.0	.0904	11.07
38	264.1	233.3	929.2	1162.5	.0927	10.79
39	265.6	234.8	928.1	1162.9	.0949	10.53
40	267.2	236.4	927.0	1163.4	.0972	10.28
41	268.7	237.9	926.0	1163.9	.0995	10.05
42	270.1	239.4	924.9	1164.3	.1018	9.83
43	271.6	240.8	923.9	1164.7	.1041	9.61
44	273.0	242.3	922.9	1165.2	.1063	9.40
45	274.3	243.7	921.9	1165.6	.1086	9.21
46	275.7	245.1	920.9	1166.0	.1109	9.02
47	277.0	246.4	920.0	1166.4	.1131	8.84
48	278.3	247.7	919.1	1166.8	.1154	8.67
49	279.6	249.1	918.1	1167.2	.1177	8.50
50	280.9	250.3	917.3	1167.6	.1199	8.34
51	282.2	251.6	916.4	1168.0	.1222	8.19
52	283.4	252.9	915.5	1168.4	.1244	8.04
53	284.6	254.1	914.6	1168.7	.1267	7.89
54	285.8	255.3	913.8	1169.1	.1289	7.76
55	287.0	256.5	912.9	1169.4	.1312	7.62
56	288.1	257.7	912.1	1169.8	.1334	7.50
57	289.3	258.9	911.3	1170.2	.1357	7.37
58	290.4	260.0	910.5	1170.5	.1379	7.25
59	291.5	261.1	909.7	1170.8	.1401	7.14
60	292.6	262.3	908.9	1171.2	.1424	7.02

TABLE LXIX—Continued

Absolute Pressure	Temperature Degrees Fahr.	Heat Units above 32 Degrees Fahr. Contained in 1 Pound of Steam			Weight of 1 Cubic Foot in Pounds	Volume of 1 Pound in Cubic Feet
		In Water	Latent Heat	Total Heat		
61	293.7	263.3	908.2	1171.5	.1446	6.92
62	294.7	264.4	907.4	1171.8	.1468	6.81
63	295.8	265.5	906.6	1172.1	.1491	6.71
64	296.8	266.6	905.9	1172.5	.1513	6.61
65	297.8	267.6	905.2	1172.8	.1535	6.52
66	298.8	268.7	904.4	1173.1	.1557	6.42
67	299.8	269.7	903.7	1173.4	.1579	6.33
68	300.8	270.7	903.0	1173.7	.1602	6.24
69	301.8	271.7	902.3	1174.0	.1624	6.16
70	302.8	272.7	901.6	1174.3	.1646	6.08
71	303.7	273.6	901.0	1174.6	.1668	6.00
72	304.7	274.6	900.3	1174.9	.1690	5.92
73	305.6	275.6	899.6	1175.2	.1712	5.84
74	306.5	276.5	898.9	1175.4	.1734	5.77
75	307.4	277.4	898.3	1175.7	.1756	5.69
76	308.3	278.4	897.6	1176.0	.1778	5.62
77	309.2	279.3	897.0	1176.3	.1800	5.56
78	310.1	280.2	896.3	1176.5	.1822	5.49
79	311.0	281.1	895.7	1176.8	.1844	5.42
80	311.9	282.0	895.1	1177.1	.1866	5.36
81	312.7	282.8	894.5	1177.3	.1888	5.30
82	313.6	283.7	893.9	1177.6	.1910	5.24
83	314.4	284.5	893.3	1177.8	.1932	5.18
84	315.3	285.4	892.7	1178.1	.1954	5.12
85	316.1	286.2	892.1	1178.3	.1976	5.06
86	316.9	287.1	891.5	1178.6	.1998	5.01
87	317.7	287.9	890.9	1178.8	.2020	4.95
88	318.5	288.8	890.3	1179.1	.2042	4.90
89	319.3	289.6	889.7	1179.3	.2063	4.85
90	320.1	290.4	889.2	1179.6	.2085	4.80
91	320.9	291.2	888.6	1179.8	.2107	4.75
92	321.7	291.9	888.1	1180.0	.2129	4.70
93	322.4	292.8	887.5	1180.3	.2151	4.65
94	323.2	293.5	887.0	1180.5	.2173	4.60
95	323.9	294.3	886.4	1180.7	.2194	4.56
96	324.7	295.1	885.9	1181.0	.2216	4.51
97	325.4	295.8	885.4	1181.2	.2238	4.47
98	326.2	296.6	884.8	1181.4	.2260	4.43
99	326.9	297.3	884.3	1181.6	.2281	4.38
100	327.6	298.1	883.8	1181.9	.2303	4.34
101	328.3	298.8	883.3	1182.1	.2325	4.30
102	329.1	299.6	882.7	1182.3	.2346	4.26
103	329.8	300.3	882.2	1182.5	.2368	4.22
104	330.5	301.0	881.7	1182.7	.2390	4.19
105	331.2	301.7	881.2	1182.9	.2411	4.15
106	331.9	302.4	880.7	1183.1	.2433	4.11
107	332.6	303.2	880.2	1183.4	.2455	4.07

TABLE LXIX—Continued

Absolute Pressure	Temperature Degrees Fahr.	Heat Units above 32 Degrees Fahr. Contained in 1 Pound of Steam			Weight of 1 Cubic Foot in Pounds	Volume of 1 Pound in Cubic Feet
		In Water	Latent Heat	Total Heat		
108	333.2	303.9	879.7	1183.6	.2476	4.04
109	333.9	304.6	879.2	1183.8	.2498	4.00
110	334.6	305.3	878.7	1184.0	.2519	3.97
111	335.3	305.9	878.3	1184.2	.2541	3.94
112	335.9	306.6	877.8	1184.4	.2563	3.90
113	336.6	307.3	877.3	1184.6	.2584	3.87
114	337.2	308.0	876.8	1184.8	.2606	3.84
115	337.9	308.6	876.4	1185.0	.2627	3.81
116	338.5	309.3	875.9	1185.2	.2649	3.78
117	339.2	310.0	875.4	1185.4	.2670	3.75
118	339.8	310.6	875.0	1185.6	.2692	3.72
119	340.4	311.3	874.5	1185.8	.2713	3.69
120	341.1	311.9	874.1	1186.0	.2735	3.66
121	341.7	312.5	873.6	1186.1	.2757	3.63
122	342.3	313.1	873.2	1186.3	.2778	3.60
123	342.9	313.8	872.7	1186.5	.2799	3.57
124	343.5	314.4	872.3	1186.7	.2821	3.55
125	344.1	315.1	871.8	1186.9	.2842	3.52
126	344.7	315.7	871.4	1187.1	.2864	3.49
127	345.3	316.3	871.0	1187.3	.2885	3.47
128	345.9	316.9	870.5	1187.4	.2907	3.44
129	346.5	317.5	870.1	1187.6	.2928	3.42
130	347.1	318.1	869.7	1187.8	.2950	3.39
131	347.7	318.7	869.3	1188.0	.2971	3.37
132	348.3	319.3	868.9	1188.2	.2992	3.34
133	348.9	319.9	868.4	1188.3	.3014	3.32
134	349.4	320.5	868.0	1188.5	.3035	3.30
135	350.0	321.1	867.6	1188.7	.3057	3.27
136	350.6	321.7	867.2	1188.9	.3078	3.25
137	351.1	322.3	866.8	1189.1	.3099	3.23
138	351.7	322.8	866.4	1189.2	.3121	3.20
139	352.3	323.4	866.0	1189.4	.3142	3.18
140	352.8	324.0	865.6	1189.6	.3163	3.16
141	353.4	324.6	865.1	1189.7	.3185	3.14
142	353.9	325.1	864.8	1189.9	.3206	3.12
143	354.5	325.7	864.4	1190.1	.3227	3.10
144	355.0	326.2	864.0	1190.2	.3249	3.08
145	355.6	326.8	863.6	1190.4	.3270	3.06
146	356.1	327.4	863.2	1190.6	.3291	3.04
147	356.6	327.9	862.8	1190.7	.3313	3.02
148	357.2	328.5	862.4	1190.9	.3334	3.00
149	357.7	329 0	862.0	1191.0	.3355	2.98
150	358.2	329.6	861.6	1191.2	.3376	2.96
160	363.3	334.9	857.9	1192.8	.3589	2.79
170	368.2	339.9	854.4	1194.3	.3801	2.63
180	372.9	344.7	851.0	1195.7	.4012	2.49
190	377.4	349.3	847.7	1197.0	.4223	2.37
200	381.6	353.7	844.6	1198.3	.4433	2.26

TABLE LXX. Properties of Saturated Steam of from 32 Degrees to 212 Degrees Fahr. at Pressures Under One Atmosphere

Temperature Degrees Fahr.	Pressure		Total Heat of One Pound Reckoned from Water at 32 Degrees Fahr. Units	Weight of 100 Cubic Feet Pounds	Volume of One Pound of Vapor Cubic Feet
	Inches of Mercury	Pounds per Square Inch			
32	.181	.089	1091.2	.031	3226
35	.204	.100	1092.1	.034	2941
40	.248	.122	1093.6	.041	2439
45	.299	.147	1095.1	.049	2041
50	.362	.178	1096.6	.059	1695
55	.426	.214	1098.2	.070	1429
60	.517	.254	1099.7	.082	1220
65	.619	.304	1101.2	.097	1031
70	.733	.360	1102.8	.114	877.2
75	.869	.427	1104.3	.134	746.3
80	1.024	.503	1105.8	.156	641.0
85	1.205	.592	1107.3	.182	549.5
90	1.410	.693	1108.9	.212	471.7
95	1.647	.809	1110.4	.245	408.2
100	1.917	.942	1111.9	.283	353.4
105	2.229	1.095	1113.4	.325	307.7
110	2.579	1.267	1115.0	.373	268.1
115	2.976	1.462	1116.5	.426	234.7
120	3.430	1.685	1118.0	.488	204.9
125	3.933	1.932	1119.5	.554	180.5
130	4.509	2.215	1121.1	.630	158.7
135	5.174	2.542	1122.6	.714	140.1
140	5.860	2.879	1124.1	.806	124.1
145	6.662	3.273	1125.6	.909	110.0
150	7.548	3.708	1127.2	1.022	97.8
155	8.535	4.193	1128.7	1.145	87.3
160	9.630	4.731	1130.2	1.333	75.0
165	10.843	5.327	1131.7	1.432	69.8
170	12.183	5.985	1133.3	1.602	62.4
175	13.654	6.708	1134.8	1.774	56.4
180	15.291	7.511	1136.3	1.970	50.8
185	17.044	8.375	1137.8	2.181	45.9
190	19.001	9.335	1139.4	2.411	41.5
195	21.139	10.385	1140.9	2.662	37.6
200	23.461	11.526	1142.4	2.933	34.1
205	25.994	12.770	1143.9	3.225	31.0
210	28.753	14.126	1145.5	3.543	28.2
212	29.922	14.700	1146.1	3.683	27.2

The temperature of steam at different pressures can be found in Table LXIX. To use this table, add 14.7 to the reading of the gauge to get absolute pressure; the quantities desired will be opposite this figure.

Usually 15 pounds added to the gauge pressure to get the absolute pressure will be sufficiently accurate for all ordinary purposes.

In the foregoing table the properties of saturated steam are given for pressures above atmosphere, or for gauge pressures. In Table LXX, on the other hand, will be found the properties of saturated steam at less than atmospheric pressures, or at partial vacuums.

BOOSTER HEATERS.—A higher temperature is sometimes required for water in a building for some particular purpose, than is needed for the entire building. In such cases a booster heater can be used to heat the water for the special purposes. This is done by passing the hot water through a heater with steam coil, thereby raising the temperature of the hot water to the required degree. There are no cold water connections to a booster.

Heating Water with Gas

KINDS OF GAS.—There are four different kinds of gas which are used for water heating. They are *coal gas, oil gas, water gas,* and *natural gas.* Acetylene gas and producer gas are not considered here. Coal gas is produced by the distillation or driving off of the light hydrocarbons, or gas, from coal. Nothing is added to the gas, and the by-products of distillation are coke, tar and ammonia. There is very little coal gas used now commercially.

Oil gas is made in much the same manner as coal gas, by the process known as destructive distillation. This consists of heating the oil to a very high temperature, thereby causing the heavy hydrocarbons to break up into the lighter or gaseous form. Animal and vegetable fats and oils, waste fats that occur in the manufacture of woolens, and ordinary rosins are used as well as petroleum in the manufacture of oil gas.

Water gas, which is probably more extensively manufactured than any other kind of gas for general distribution, is made commercially by the contact of steam with incandescent carbon in the form of anthracite coal or coke. The steam is decomposed, the hydrogen being separated from the oxygen. The oxygen then takes up carbon from the coal or coke.

This gas would burn with a non-luminous flame and would be useless for lighting except with incandescent mantels, so in practice the water gas is enriched with oil gas which furnishes the hydrocarbon necessary to make a luminous flame, but adds very little to the heating quality of the gas.

The illuminating power of gas is determined by its *candlepower.* The candlepower is measured while the gas is burning in an open burner at the rate of five cubic feet per hour, by comparing the light given off with that of a *standard candle.* A standard candle is one that will burn 120 grains of spermaceti per hour.

As a standard of quality, the candle power of gas is giving way to the more rational one of heat value, gas being used now almost exclusively for heating, not for lighting.

HEAT UNITS IN GAS.—There is no one definite number of heat units, B. T. U., that can be given as the heat value of gas. As has already been pointed out, there are three processes of manufacture of artificial gas, also natural gas, all of which are used throughout the country. Of the manufactured gases, two or more kinds are sometimes combined, as, for instance, when oil gas is added to water gas, so that the exact amount of heat given off by a cubic foot of gas will depend upon the standard of the local gas company, which should be taken into account when computing the amount of water that can be heated by gas in that locality.

Artificial gas is generally said to contain 700 heat units, and natural gas from 740 to 1117 heat units, according to the territory where the natural gas is produced. As a matter of fact, the heat contained in manufactured gas varies from 500 to 600 B. T. U. It seldom exceeds 650. It is governed by laws in some states, and the present

tendency seems towards establishing a standard of 525 B. T. U. per cubic foot of manufactured gas.

AUTOMATIC WATER HEATERS.*—A thorough understanding of what is meant by the rated capacity of a heater must be had before an intelligent selection of size can be made.

Every instantaneous automatic and multi-coil storage heater has a definite rated capacity, which expresses in the case of the instantaneous automatic water heater the number of gallons per minute, and in the multi-coil storage heater the number of gallons per hour, that the heater will deliver at any given rise in temperature with its normal gas consumption.

For the sake of convenience the heaters have generally been numbered to correspond to the number of gallons they will deliver, raising the temperature 63° F. Therefore, a No. 4 heater has a rated capacity at 63° rise in temperature of 4 gallons per minute, but should the required rise be 80° instead of 63°, the rated capacity of a 4-gallon heater would be 3.15 gallons instead of 4 gallons, while if the required temperature rise be only 50°, the rated capacity of the 4-gallon heater would be 5.04 gallons per minute. In the case of the multi-coil storage heater, the rated capacity of the No. 200 heater at 63° temperature rise is 200 gallons per hour, while if the required temperature rise be 80°, the rated capacity will be 157 gallons per hour, but should the temperature rise required be only 50°, the rated capacity would be 252 gallons per hour. The above is based upon the consumption of 1 cubic foot of gas having a heat value of 650 B. T. U. for each gallon of water raised 63°.

A rule by which the rated capacity of any instantaneous automatic or multi-coil storage heater for any given temperature rise may be found is as follows:

Rule—Multiply the size of the heater by 63, the result of which will be the degree-gallon capacity of the heater; divide this result by the number of degrees the temperature is to be raised and the result will be the rated capacity of

*Data compiled by American Gas Association.

the heater at that temperature rise. For convenience, the formula would be as follows:

$$\frac{\text{Size number} \times 63}{\text{Temperature rise in degrees}} = \text{Rated capacity of heater.}$$

From this it follows that if the required flow and temperature raise is known, by the use of the following formula the size number of the heater may be determined.

$$\frac{\text{Flow} \times \text{temperature rise}}{63} = \text{size number of heater.}$$

For example: If it is required to deliver 4.50 gallons per minute with a temperature rise of 90°

$$\frac{4.50 \times 90}{63} = 6.43.$$

Therefore, the size heater to be used in this case would be an 8-gallon per minute heater, since the result is greater than a No. 6, and less than a No. 8, the next larger size.

Where heaters are not numbered as described above the rated capacity should be ascertained and this quantity substituted for the size number in the above formula. If the rated capacity is not given as at 63°, the degree rise given should be substituted also.

Table LXXI shows the sizes manufactured in the instantaneous automatic water heater and Table LXXII the

TABLE LXXI. Capacities of Instantaneous Automatic Water Heaters

Gals. per min.	Temperature rise in Degrees										
	50	60	70	80	90	100	110	120	130	140	150
1½	1.89	1.57	1.35	1.18	1.05	0.95	0.86	0.78	0.73	0.68	0.63
2½	3.15	2.62	2.25	1.97	1.75	1.58	1.43	1.31	1.21	1.12	1.05
3	3.78	3.15	2.70	2.36	2.10	1.89	1.72	1.58	1.45	1.35	1.26
4	5.05	4.20	3.60	3.15	2.80	2.52	2.29	2.10	1.94	1.80	1.68
6	7.58	6.30	5.40	4.73	4.20	3.87	3.52	3.23	2.98	2.76	2.58
8	10.10	8.40	7.20	6.30	5.60	5.04	4.59	4.20	3.88	3.60	3.36

Note—In some cases makers of heaters do not number their heaters as above, but state the capacity of the heaters in the catalogs. In those cases substitute the per minute capacity at 63° rise for the maker's number to use this table.

multi-coil storage heater, together with their capacities per minute and per hour respectively, at various temperature rises.

TABLE LXXII. Capacities of Multi-Coil Storage Heaters

Gals. per hour	Temperature rise in Degrees										
	50	60	70	80	90	100	110	120	130	140	150
100	126	105	90	78.8	70	63	57.2	52.5	48.4	45	42
200	252	210	180	157.5	140	126	114.5	105.0	97.0	90	84
300	378	315	270	236.0	210	189	172.0	158.0	145.0	135	126
400	505	420	360	215.0	280	252	229.0	210.0	194.0	180	168
500	630	525	450	394.0	350	315	287.0	262.0	242.0	225	210

Note—Where heaters are not numbered according to gallons per hour at 63° rise, substitute the rating for the size number to use this table.

It will be noted from the foregoing that it is a fundamental mistake to believe that there is but one rated capacity for each heater, and that it is expressed by the size number of the heater and that it applies for any rise of temperature.

As the temperature of the water is increased, the per minute capacity of the heater is correspondingly less, and it will be noted from the table that when an unusually high temperature is desired, the capacity of the heater is very considerably reduced.

Since the greater number of automatic water heaters are installed in residences, the following recommendations, based on general practice, may be used as a guide in determining the proper size heater to install in different size residences:

3-gallon per minute heater or 40-gallon multi-coil storage system—Residences having one bath-room and kitchen sink, small family.

4-gallon per minute heater or 50-gallon multi-coil storage system—Residences having one private bath-room, servants' bath-room, kitchen sink, laundry trays.

6-gallon per minute heater or 66 or 80-gallon multi-coil storage system—Residences having two private bath-rooms, servants' bath, one or two bedroom lavatories, kitchen sink and laundry trays.

8-gallon per minute heater or 100-gallon multi-coil storage system—Residences having three or four private baths, servants' bath-room, two or three bedroom lavatories, kitchen and pantry sinks, large laundry. Comparatively small family.

Due to the large per minute gas requirements for the 8-gallon per minute heater, it is frequently found more desirable, especially in houses of great length, to supply a 3- or 4-gallon per minute heater for the supply of hot water for the entire laundry and kitchen, and install a 6-gallon per minute heater for the supply of water to various bath-rooms of the huse.

100-gallon per hour heater with 100, 120 or 150-gallon tanks—Large residences having three to five bath-rooms, bath-room lavatories, large kitchen sink, pantry sink and laundry. Flat buildings with six apartments of four or five rooms each.

200-gallon per hour heater with 120, 150 or 250-gallon tanks—Large residences having seven to ten bath-rooms, large kitchen sink, pantry sink, dishwashing machine, large laundry. Apartment buildings having ten to fourteen flats of five or six rooms each.

300-gallon per hour heater with 250, 300 or 365-gallon tanks—Large residences having seven to ten bath-rooms, large kitchen sink, pantry sink, dish washing machine, large laundry. Apartment buildings having ten to fourteen flats of five or six rooms each.

400-gallon per hour heater with 365 or 425-gallon tanks—Large apartment buildings having fourteen to twenty-five flats of five, six or seven rooms. Very large city homes. Thirty to fifty-room hotels.

500-gallon per hour heater with 425, 500 or 600-gallon tanks—Apartment buildings having twenty to thirty flats of five, six or seven rooms each. Very large city homes. Forty to sixty-room hotels.

Larger requirements may be met by using what are known as duplex storage systems, in which two or more multi-coil storage heaters are connected to a single tank of proper storage capacity.

While the above table may be used as a guide, unusual conditions may make it necessary to depart from it.

The street main and the service from the main to the meter must be of sufficient size to supply the maximum demands of the heater.

The gas supply should be run direct from the meter to the thermostat without any branches, and should be large enough for the maximum amount of gas required by the heater.

As in the case of the instantaneous automatic water heater, a tag should be attached to the meter, stating that a multi-coil storage system is installed.

The size of gas pipe, meter, and flue for automatic gas heaters can be found in Table LXXIII.

TABLE LXXIII. Size of Pipes for Automatic Storage Systems

Size of Heater Gals.	Water Supply to System Inches	Water Supply to Fixtures Inches	Gas Meter Lt.	Gas Line to Heater Inches	Diameter of Flue Inches
30	¾	¾	10	¾	3
50	1	1	10	¾	4
100	1 to 1½	1 to 1⅛	10	1	4
200	1 to 1½	1 to 1½	30	1	6
300	1⅛ to 2	1½ to 2	45	1½	6
400	1½ to 2	1½ to 2	60	1½	7
500	2 to 2½	2 to 2½	80	2	8

In Tables LXXIV to LXXX inclusive, will be found records of the actual performance of water heaters in several different types of buildings. The data were compiled by the American Gas Association, and the gas used had an approximate heat value of 650 B. T. U. per cubic foot.

TABLE LXXIV. Water Heating Data for Office Building

Installation No.	System	Fixtures			Ordinary Day	Entire Week
1	31 Section Boiler, Thermo control, 1,000 gal. storage, Instantaneous Hot Water service heater	250 Hot Water Fixtures	Hot water used, gals.	Monday to Friday inclusive	6395	35,200
			Gas Consumed, cu. ft.		11311	69,200
			Temperature rise, degrees F.		65.6	65.8
			Temperature water delivered, degrees F.		135.9	136.8
			Gas per gal., cu. ft.		1.76	1.96

TABLE LXXV. Water Heating Data for Hotel Building

Installation No.	System	Fixturs		Maximum Day	Average Day	Entire Week
1	41 Section Hot water Boiler, Circulating System, 950 gal. tank	155 Bathtubs	Hot water used, gals.	19732	17317	123637
		170 Washbasins	Gas consumption, cu. ft.	22100	19850	141200
		154 Showers	Temperature rise, deg. F.	60	67.6	66.3
		7 Kitchen sinks	Temperature water delivered, deg. F.	124	131.6	130.3
		10 Slop sinks	Gas per gal., cu. ft.	1.12	1.14	1.14
		1 Dishwasher	Ratio hot water to total, 1:3.28			
			Hot water maximum hour, 1050 gals.			
			Ratio maximum hour to 24 hour, 1:16.14			
			Heater capacity 820 gals. per hour			
			Storage capacity, 950 gals.			

TABLE LXXVI. Water Heating Data for Club

Installation No.	System	Fixtures		Maximum Day	Ordinary Day	Entire Week
1 12 stories and Basement	Summer months, 1 hot water heater, thermo control, circulating system, 500 gal. tank	38 Tubs 55 Basins 14 Showers 5 Sinks 19 Slop sinks	Hot water used, gals	4687.5	3381	24436
			Gas consumed, cu. ft	8900	8475	59466
			Temperature rise, deg. F	72	75.5	75.2
			Temperature water delivered, deg. F	130	134.7	134.4
			Gas per gal., cu. ft	1.89	2.5	2.43
			H. W. maximum hour, 501 gals			
			Ratio maximum hour to 24 hour, 1:7.86			
			Maximum day demand, 4687.5 gals			
			Heater capacity, 200 gals. per hour			
			Storage capacitty, 500 gals. per hour			

TABLE LXXVII. Water Heating Data for Loft Building

Installation No.	System	Fixtures		Maximum Day	Ordinary Day	Entire Week
1	41 Section Hot Water Boiler, Return System, 860 gal. storage	Office help 600	Hot water used, gals	11812	7111.5	38362.5
		Printers (workers) .. 1100	Gas consumed, cu. ft	22100	10440	56700
		Electrotypers 66	Temperature rise, degrees F	85	73	76
		Building mechanics. 50	Temperature water delivered, degrees F.	147	137	140
			Gas per gal., cu. ft	1.87	1.46	1.48
		1810	Ratio maximum hour to 24 hour, 1:14.7			
			Hot water maximum hour, 802 gals.			
			Heater capacity, 820 gal. per hour			
			Storage capacity, 860 gal.			

TABLE LXXVIII. Water Heating Data for Laundry Purposes

Installation No.	System	Fixtures		Single Day	Single Week
1	27 Section Hot Water Boiler, thermo control, 500 gal. storage tank.	Special wet wash laundry 8 individual washing machines. Clothes kept separate.	TANK AND PIPING UNCOVERED		
			Hot water used, gals.	2460	16927.5
			Gas consumed, cu. ft.	7300	34900
			Temperature rise, degrees F.	72.3	62.8
		NOTE:	Temperature water delivered, degrees F.	136.6	131.2
		Total No. washes... 96	Gas per gal., cu. ft.	2.96	2.06
		Hot water used, gals. 6150	TANK AND PIPING COVERED		
		Gas consumed, cu.ft. 8900	Hot water used, gals.	6150	19687.5
		Gas per wash, cu.ft. 92.7	Gas consumed, cu. ft.	8900	35200
			Temperature rise, degrees F.	83.4	80.3
			Temperature water delivered, degrees F.	125.4	125.00
			Gas per gal., cu. ft.	1.45	1.78

TABLE LXXIX. Water Heating Data for Apartments

Installation No.	System	Fixtures		Maximum Day	Minimum Day	Entire Week
1 5 stories Cellar Store on 1st Floor	1 Automatic instantaneous Water heater	Cellar	Hot water used, gals	742.5	593.7	4304.5
		1 sink	Gas consumed, cu. ft.	1400	1166	8400
		Store	Temperature rise, deg. F	107	123	120
		1 sink	Temperature water delivered, deg. F	150	164	162
		1 bath	Gas per gal., cu. ft.	1.88	1.96	1.95
		2 tubs	After reducing temperature of water del.			
		Apartments	Hot water used, gals	832.5	693.7	4995
		15 basins	Gas consumed, cu. ft.	1100	917	6600
		7 baths	Temperature rise, deg. F	80	79	79
		7 sinks	Temperature water delivered, deg. F	125	123	123
		2 tubs	Gas per gal., cu. ft.	1.32	1.32	1.32
		15 people				
2 Residence converted to apartments, 4 stories and Cellar	1 hot water heater, Non-circulating 25 gal. tank	4 basins	Hot water used, gals	262.5	195	1463.5
		2 tubs	Gas consumption, cu. ft.	700	516	3800
		3 baths	Temperature rise, deg. F	102	97	98
		9 people	Temperature water delivered, deg. F	145	141	142
			Gas per gal., cu. ft.	2.66	2.65	2.65
3 4 stories store, 9 apartments	3 Section hot water boiler, thermo control, 180 gal. tank	9 baths	Hot water used, gals	772.5	415	3262.5
		9 showers	Gas consumption, cu. ft.	1500	1000	7500
		9 basins	Temperature rise, deg. F	82	85	84
		9 apartments, 13 people	Temperature water delivered, deg. F	132	134	134
			Gas per gal., cu. ft.	1.94	2.40	2.29
4 6 story basement and cellar	6 section hot water boiler, circulating system 220 gal. tank	2 rooms and bath per story	Hot water used, gals	405	339	2437
			Gas consumed cu. ft.	1300	1169	8300
		12 baths	Temperature rise, deg. F	75	76	75.6
		12 basins	Temperature water delivered, deg. F	125	124	124.4
			Gas per gal., cu. ft.	3.2	3.4	3.4

Note—24 day period, hot water used, 6412 gals.; Gas, 22300 cu. ft.

TABLE LXXIX. Water Heating Data for Apartments—Continued

Installation No.	System	Fixtures		Maximum Day	Minimum Day	Entire Week
5 6 story and basement 12-9 room apartments	11 section hot water boiler Thermo. control, circulating system, 250 gal. tank	25 baths 11 showers 13 basins 12 sinks 26 tubs 53 people	Hot water used, gals.	3000	2485	17910
			Gas consumption, cu. ft.	4700	4050	29000
			Temperature rise, deg. F	93	91	91.5
			Temperature water delivered, deg. F	132	131	131
			Gas per gal., cu. ft	1.56	1.63	1.62

Note—4 week period, hot water used, gals., 64425; gas consumption, cu. ft., 111100; hot water maximum hour, gals., 330; ratio maximum hour to 24 hour, 1:9.09; heating capacity, per hour, gals. 220; storage capacity, gals., 250.

TABLE LXXX. Water Heating Data for Residences

Installation No.	System	Fixtures		Maximum Day	Ordinary Day	Entire Week
1	3 section hot water	3 baths	Hot water used, gals.	328.5	249.5	1757
4 stories	boiler, 120 gal. tank	3 tubs	Gas consumed, cu. ft.	495	412	2719
basement		2 sinks	Temperature rise, deg. F.	78	78	73.4
and		3 basins	Temperature water delivered, deg. F.	122	123	122
cellar			Gas per gal., cu. ft.	1.51	1.65	1.55
2	3 section automatic	4 baths	Hot water used, gals.	230.6	143	1110
3 stories	hot water boiler, 120	3 basins	Gas consumed, cu. ft.	550	415	3025
basement	gal. tank	3 sinks	Temperature rise, deg. F.	80¼	77.3	77
cellar		3 laundry tubs	Temperature water delivered, deg. F.	131¼	129.5	129
			Gas per gal., cu. ft.	2.38	2.89	2.73
3	3 section hot water	6 baths	Hot water used, gals.	300	192.5	1455
3 stories	boiler, 150 gal. tank,	8 basins	Gas consumed, cu. ft.	600	450	3300
basement	non-circulating	2 sinks	Temperature rise, deg. F.	75	75.5	75.4
cellar		5 tubs	Temperature water delivered, deg. F.	130	130.5	130.4
		(3 in family 1 servant)	Gas per gal., cu. ft.	2.0	2.34	2.27
4	3 section hot water	3 baths	Hot water used, gals.	217.5	115	907.5
3 stories	boiler, 120 gal. tank,	3 basins	Gas consumed, cu. ft.	350	266	1920
basement	non-circulating	4 sinks	Temperature rise, deg. F.	57	61	60.5
cellar		2 tubs	Temperature water delivered, deg. F.	125	129	128.5
		(5 in family)	Gas per gal., cu. ft.	1.61	2.31	2.15

CHAPTER XXVIII

TANKS FOR STORING HOT WATER

RANGE BOILERS.—Range boilers are storage tanks for hot water. They are usually located near the kitchen range, and the water in them is heated by the waterback in the range. Some boilers are made of copper, some of wrought-iron and some of steel. Wrought iron and steel boilers are made plain, painted and galvanized. Range boilers of larger capacity than 200 gallons are not made in stock sizes.

COPPER BOILERS.—Copper boilers are made for both low pressure and for heavy pressure water supplies. A low pressure boiler is made of light cold-drawn copper, polished on the outside and generally tinned on the inside. They are tested to about 75 pounds pressure, and are suitable only for systems where the pressure does not exceed 20 pounds per square inch. The chief objection to boilers of this type is their liability to collapse from atmospheric pressure when the water is in any way siphoned from them. Copper boilers, while they cost more, are better than iron boilers for storage purposes. They are cheaper in the end as they last longer, and rust will not accumulate in the boiler to discolor clothes in washing, as it does with black or galvanized iron boilers.

SAFETY COPPER BOILERS.—Safety copper boilers are made with internal brass ribs to reinforce them. In some types of safety boilers, the internal rib runs spirally around the boiler from one end to the other. Reinforcing boilers makes them proof against collapsing from external pressure.

Safety copper boilers are tested before shipping. There are two grades of safety boilers: one tested to 150 pounds pressure and guaranteed to stand a working pressure of 100 pounds; the other tested to 250 pounds pressure and guaranteed to stand a working pressure of 150 pounds. Both grades are guaranteed against collapsing, provided no check valve is used on the cold water supply to the boiler. If a check valve is used it confines to the boiler the water that

would otherwise expand back into the water mains, when the water in the boiler is heated, and expansion might subject the boiler to a pressure far in excess of what it is guaranteed to stand. Copper boilers are the best-appearing range boilers made. They are easily stained green, however, and they radiate heat to surrounding objects at a greater rate than do iron boilers.

GALVANIZED RANGE BOILERS.—These boilers are made for both standard and extra heavy pressures. The standard boilers are generally marked tested to 150 pounds pressure and rated to stand a working pressure of 85 pounds.

The extra heavy boilers are marked tested to a pressure of 200 pounds and rated to stand a working pressure of 150 pounds. Galvanized range boilers are made both single and double riveted. Single rivet boilers have but one row of rivets along the seam, while double rivet boilers have a double row of rivets along the seam.

Galvanized range boilers are galvanized after being made, and are galvanized both inside and out. The coating of zinc deposited on both inner and outer surfaces helps to make the joints and rivets water-tight. Galvanized range boilers are not all guaranteed, and notwithstanding the stenciled statement printed on each boiler that it has been tested to a certain pressure, they are seldom tested before leaving the factory, and are not suitable for pressure of more than one-half that which they are marked tested.

MUD DRUM FOR BOILERS.—In localities where the water supply carries large quantities of clay or loam in suspension, a boiler with a mud drum or sediment chamber, Fig. 131, may be used. The boiler will then serve as a settling basin and most of the suspended matter will settle to the bottom of the boiler and into the sediment space. It can then be washed out at suitable intervals by opening the blow-off cock at the bottom of the boiler. If the particles held in suspension in the water are comparatively coarse, about fifty per cent. will be removed by sedimentation.

HOT WATER TANKS.—Hot water tanks are large wrought-iron or steel storage tanks of 200 gallons or more capacity, used in connection with water heaters. They are

generally used plain or painted, but are seldom galvanized. Large hot water tanks are seldom carried in stock, but are made to order. A sketch, showing the location and size of all outlets should accompany all orders for hot water tanks. The size of the tank and pressure of the water should always be considered when ordering, and when storage tanks are extremely large and subject to great internal pressure, stay bolts and cross braces should be used to give the tank additional strength. Boilers and tanks, of whatever type or make, should be tested and guaranteed to stand a pressure of at least double the static pressure of the water to be stored. This is to provide a factor of safety for occasions when the internal pressure is increased by the expansion of the water when heated, or the increased pressure, perhaps double the static pressure, due to water hammer.

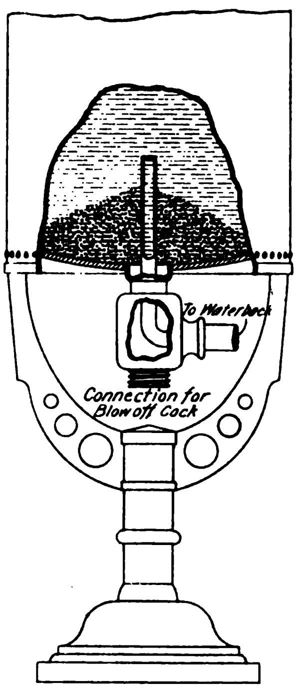


Fig. 131
Sediment Chambers for Boiler

SUPPORTS FOR BOILERS AND TANKS. — Range boilers are usually placed alongside the kitchen range in a vertical position, where they rest upon a cast iron boiler stand. When range boilers are placed horizontally they usually rest on iron brackets attached to the top or back of the range. Horizontal storage tanks are generally supported by iron bands attached to the iron floor beams above. When they are set vertically they are supported by iron frames or legs. Large tanks should have cross braces within to give them strength to withstand racking stresses.

PROPORTIONING SIZE OF TANK AND BOILERS.—Range boilers and heater tanks are used to store water heated by waterback or water heater during periods when hot water

is not being drawn. It thus provides a supply to draw upon when hot water is used faster than it can be heated by the waterback or heater. Also, it allows a smaller heater to be used than would be the case if water were drawn direct from a heater and had to be heated as fast as used.

The size of a tank for storing hot water should bear a certain relation both to the capacity of the heater and to the number of gallons of hot water used daily. If the tank is too large for the heater there will never be a supply of hot water in the tank, and if the tank is too small the water will become heated to above 212 degrees, and when released from the faucet will flash instantly into steam; also in many cases it will cause a rattling, snapping sound in the heater.

An ordinary range has a waterback with a heating surface of about 110 square inches exposed to the fire. A waterback of such a size will ordinarily heat sufficient water for an average size family. It can be used in connection with any size boiler, from 35 to 50 gallons capacity. The size of the boiler should depend upon the probable amount of hot water that will be used daily. If the water is used uniformly throughout the day, and almost as fast as it is heated, a 35-gallon boiler will be sufficiently large. If, on the other hand, the water is drawn intermittently, with long intervals between drafts, a larger boiler should be used to store the water heated during the intervals.

In public and semi-public buildings, where large quantities of hot water are used, the heater must be large enough to heat water as fast as it will probably be used during periods of average consumption, and the hot water tank should be large enough to store sufficient water for one hour's maximum supply. For instance, in an apartment house where the probable maximum consumption of hot water would equal 250 gallons per hour, and the average consumption 125 gallons per hour, the heater should be capable of heating at least 125 gallons per hour, from ordinary temperature to 180 degrees, and in hotels and laundries the tank should have a storage capacity of 250 gallons.

Water is seldom used hotter than 130 degrees Fahrenheit, so that water of higher temperature mixed with cold

water increases the volume of available hot water. In Table LXXXI can be found the temperature at which hot water is used in buildings of different classes.

The size of hot water tank required for a large building depends so much upon conditions peculiar to that building that a satisfactory rule applicable to all cases cannot be formulated. A safe rule is to allow a sufficient capacity in the tank for the maximum hourly consumption. An approximation that will be found sufficient for most apartment houses is to allow from 5 to 7 gallons capacity in the tank for each inmate the building will accommodate. For large hotels and public institutions that have accommodations for 300 and more people, a smaller allowance, about from 2 to

TABLE LXXXI. Water Temperatures Required for Various Classes of Service

Service	Temperature required	
	Minimum	Maximum
Garages (for washing cars)	80	100
General domestic use	130	160
Laundry (hand work)	115	212
Laundry (machine work)	180	212
Barber shop (not sterilizing)	115	150
Bars and soda fountains (hot drinks)	175	212
Lavatory and cleaning uses	115	150
Baths only	110	150
Shower baths	110	150
Swimming pools	80	212
Baptistries	80	212
Dishwashing (hand work)	130	212
Dishwashing (machine)	180	212
Milk dealers (not sterilizing or pasteurizing)	115	150

4 gallons per capita, will be found sufficient. Take the case of a twelve-family apartment house in which sleeping accommodations are provided in each apartment for four people, and in the janitor's apartment for two. That would make accommodations in the building for 50 people. Allowing 7 gallons capacity in the hot-water tank for each inmate of the building, it would require a 350-gallon storage tank and a heater with a capacity of 175 gallons per hour. That

will allow each tenant of the building to take a hot bath within an hour, and have a sufficient supply for the purpose. It will take each person fifteen minutes to take a bath. At the beginning of the hour, there is in the tank 350 gallons of water at a temperature of about 200 degrees, and the heater is supplying water at that temperature at the rate of 175 gallons per hour, making a total of about 525 gallons of water at a temperature of 200 degrees available within 60 minutes. That will allow for each bather, 10½ gallons of hot water of that temperature. A bath at any temperature between 98 and 104 degrees Fahrenheit is considered a hot bath, so if we allow for the water to be used at a temperature of 110 the allowance will be safe. Assuming that the water in the street main is at a temperature of 65 degrees, then, mixing 10½ gallons of water at 200 degrees with 21 gallons of water at a temperature of 65 degrees, would give a resultant temperature to the entire mixture of 110 degrees Fahrenheit, the temperature required for bathing. Now, 30 gallons of water is sufficient for a bath, either shower or stationary; and, as it will be very seldom that all tenants will bathe within the same hour, there will invariably be a reserve supply always on hand. At the same allowance, this would give each family 120 gallons of water the first hour at a temperature of 110 degrees for washing, and about 15 gallons at a temperature of 200 degrees for washing clothes; and this allowance will be found to be sufficient for all purposes.

Each class of building must be considered separately. In an apartment house the maximum consumption of hot water would be at the hour of arising. At this time breakfast is in progress and there is so little dish washing or clothes washing being done that it is negligible. It is not likely that more than four baths can be taken in an hour in any one bath tub. As a matter of fact, the average would probably be below two, but maximums are what must be provided for.

The temperature of water in which people like to bathe varies with the individual. Baths in water from 65 to 80 degrees Fahrenheit are considered cold; in water from 80 to

92 degrees Fahrenheit, tepid; from 92 to 98 degrees Fahrenheit, warm; and from 98 to 104 degrees Fahrenheit, hot. Again the maximum must be taken, for when a person likes a hot bath he likes it hot.

The problem is, then, to find the amount of hot water that will be required per hour for each bath tub. Having that, it can be multiplied by any number of baths. An ordinary five-foot tub when filled $5\frac{1}{4}$ inches deep, contains fifteen gallons of water. That is the depth of water perhaps most generally used. At a depth of $6\frac{1}{4}$ inches, an uncomfortable depth, the tub contains twenty gallons of water.

For a hot bath at a temperature of 100 degrees, water from the heater delivered at 180 degrees, and the cold water flowing at 60 degrees, would require 7 gallons of hot water and 13 gallons of cold water. That would be equal to 28 gallons of hot water per family in an apartment house, and in a twelve-family apartment would require a hot water tank with a capacity of 12×28 equals 336 gallons, and a heater with a capacity of half that amount per hour.

It will be observed that there is a liberal factor of safety in the foregoing proportion. In the first place, there would not be four baths per family in any one hour in every apartment. In the second place, if there should be, they would not all be hot baths at a temperature of 100 degrees; and, finally, should 28 baths of 20 gallons each be taken in any one hour, at a temperature of 100 degrees, by the end of that hour the original hot water would all be drawn from the tank, but the heater would have replaced half that amount, so more than seventy-five per cent. in excess of the number of baths actually provided for could be taken.

In the chapter on heating water by gas will be found the actual amount of hot water supplied per day, per maximum hour and per week in buildings of various types.

In Table LXXXII will be found useful data to aid in estimating the quantity of hot water required per hour in various types of buildings.

BOILER AND TANK CONNECTIONS.—Connections between tank and heater should be made with copper, brass or

iron pipe. Lead pipe is unsuitable for hot water connections, as it expands when heated and upon cooling does not contract to its original length, but sags when run horizontally, thus forming traps in the pipe. Furthermore, the

TABLE LXXXII. Estimating the Hot Water Required for Various Types of Buildings

FIGURED AT FINAL TEMPERATURE OF 150 DEGREES

GALLONS OF WATER PER HOUR PER FIXTURE

	Apartment House	Club	Gymnasium	Hospital	Industrial Plant	Hotel	Laundry	Office Building.	Public Bath	Private Residence	School	Y. M. C. A.
Basin Private Lavatory......	3	3	3	3	3	3	3	3	3	3	3	3
Basin Public Lavatory......	5	5	5	8	15	8	5	5	8	...	10	10
Bath Tub......	15	15	30	30	30	30	....	....	30	15	....	30
Dish Washer.....	15	30	....	30	30	30	....	....	....	15	15	30
Foot Basin.......	3	3	12	3	....	3	....	....	....	....	....	....
Kitchen Sink.....	10	20	....	20	20	20	....	....	....	10	10	20
Laundry Stationary Tub.......	25	35	....	35	....	35	42	....	....	25	....	35
Laundry Revolving Tub (each).	75	75	....	100 to 180	....	100 to 180	100 to 180	....	100 to 180	75	....	100 to 180
Pantry Sink.....	10	20	....	20	....	20	....	....	..	10	20	20
Shower..........	80	150	150	80	200	100	....	....	200	80	200	200
Slop Sink........	20	20	....	20	20	30	10	15	15	15	20	20

Dish Washer.....220 gal. per hr. at 180 for serving capacity of 500 people

Recommended heating capacity in gals. per hour in P. C. of total water for all fixtures............	35%	60%	80%	45%	90%	75%	100%	20%	100%	50%	25%	75%
Recommended storage capacity in gals. in P. C. of total water for all fixtures..........	35%	40%	40%	45%	50%	45%	50%	40%	50%	30%	40%	50%

joints on lead pipe are liable to be melted and pull apart when the temperature of the pipe becomes very high, or should the water be siphoned out of the boiler below the

waterback, the heat from the fire would melt off the soldered joints.

Circulation between water heater and tank is impeded by friction, therefore the ends of brass, copper and iron pipe should be carefully reamed to remove the burr formed by cutting, and 45 degree bends or large radius 90 degree bends of recess pattern should be used to connect the heater and tank. Pipe of smaller diameter than 3/4-inch should never be used to connect a waterback or heater to a storage tank, and the larger the pipe used within reasonable limits the better the circulation of water.

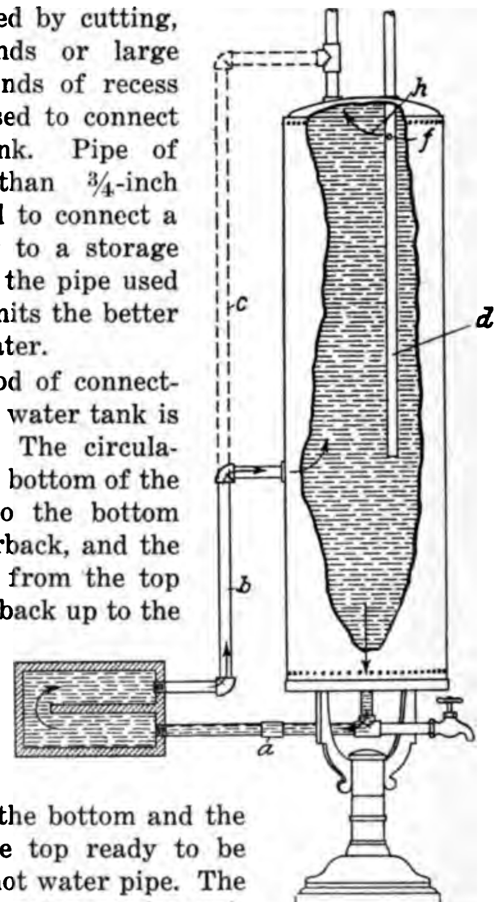


Fig. 132
Waterback Connection

The usual method of connecting a heater to a hot water tank is shown in Fig. 132. The circulation pipe, *a*, from the bottom of the tank is connected to the bottom opening of the waterback, and the flow pipe, *b*, grades from the top opening of the waterback up to the side connected to the boiler, about one-third distance from the bottom. The coldest water in a tank is always at the bottom and the hottest water at the top ready to be drawn through the hot water pipe. The temperature of the water grades uniformly from the hottest water at the top to the coldest water at the bottom of the tank. The flow pipe, *b*, must always have a rise from the waterback to the boiler. If it should be trapped, the water will not heat, and a rattling, snapping sound will be heard when a fire is started.

A better way to connect the flow pipe from a waterback to a range boiler is shown by the dotted lines, *c*. In place of entering the side of the boiler, as in the ordinary method, the flow pipe is connected to a branch in the hot water supply above the boiler. The efficiency of a heater depends upon the velocity of the circulating water, and the velocity depends upon the vertical height of the column of water, therefore with the flow pipe connected to the top of the boiler there would be a greater head, consequently a greater velocity than if the flow pipe entered the side of the boiler.

Some plumbers object to the top connection on account of the possible loss of circulation in case the water is siphoned from the boiler to the level of the hole, *f*, in the cold water tube, or to the bottom of the cold water tube, *d*. The objection is not a good one, however, for as long as the waterback remains full of water no damage can result.

If steam is generated it will either condense on the walls of the boiler or escape through the cold water pipe to the street mains. It is only when water is siphoned out of a boiler low enough to empty the waterback that it is damaged. Then, if the fire is continued in the range, the waterback becomes overheated, and is liable to crack if cold water is quickly turned into it.

The top connection might be objectionable when a circulation pipe is carried back from the fixtures. In such a case the hot water from the waterback would circulate through the hot water supply pipe, not through the boiler.

The cold water supply to a boiler usually enters the top and is conducted down through the hot water by a tube, *d*. If the tube were omitted cold water might short circuit from the cold water to the hot water pipe, as shown by the arrow, *h*, and cold water would then be drawn from the hot water faucet. If the cold water supply did not short circuit to the hot water pipe, it would mingle with the hot water at the top of the boiler, thus tending to cool it. The tube, *d*, should be tapped at *f* with a hole sufficiently large to admit air to break the siphon in case a vacuum is formed in the cold water supply pipe. The size of the hole should vary

with the size of the tube, and should have a sectional area of at least one-quarter the sectional area of the tube.

The cold water tube in a boiler should never extend below the level of where the flow pipe enters the side of the boiler. If water is siphoned from the boiler it cannot be emptied below the end of the cold water tube, and if the end of the tube is above the flow pipe from the waterback, it provides for circulation through the waterback when the flow pipe is connected to the side tapping in the boiler, and in any event it will ensure the waterback remaining full of water when the siphonage takes place. Boiler tubes for the cold water should be of brass or copper to prevent their rusting off or the vent tube choking with rust.

Many plumbers now connect the flow pipe from the waterback to both the side and to the top of a boiler, as shown by the solid lines, *b*, and dotted lines, *c*, in the illustration.

SAFETY APPLIANCES.—The most serious result of water being siphoned from a boiler is the liability of the boiler collapsing from atmospheric pressure. To prevent this, a vacuum valve can be placed close to the boiler in a branch to the cold water pipe. The vacuum valve will admit air to the boiler in case a vacuum is formed, and thus prevent the boiler being emptied and then collapsed by external pressure. A vacuum valve should be used whenever a boiler is located at such a height in a building that there is danger of the water being siphoned out when a cold water faucet is opened at a fixture below, after the water is shut off from the building.

Another way of preventing the water being siphoned from a boiler is to place a check valve in the cold water pipe. This method, however, prevents the water expanding back into the street mains when the water is heated, and might cause the boiler to burst from internal pressure unless some relief is provided. Relief is generally provided under such conditions by means of a safety valve or expansion pipe.

A safety valve, Fig. 133, consists of a valve that is held closed by means of a spring adjusted so that when the internal pressure reaches a certain intensity it will open

the valve and hold it open until the pressure is reduced, so the spring can close the valve again. A safety valve should always be used in connection with a check valve when the water is supplied from a street main. The outlet to the safety valve should be connected to a pipe leading to a sink, so that in case it blows off, the water will not be scattered over the kitchen, and scald anyone.

Combined safety and vacuum valves are sometimes used to provide safety against rupture from internal pressure or collapsing from atmospheric pressure.

An expansion pipe is used only with tank pressure. It consists of an extension of the hot water pipe up to and over the cold water supply tank, where it should return so as to discharge steam or water into the cold water tank. An expansion pipe also serves as a temperature regulator.

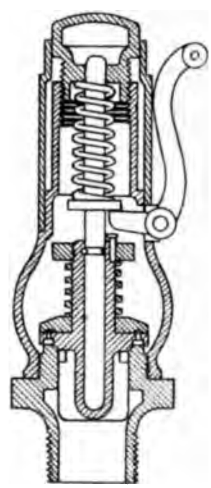


Fig. 133
Safety Valve

A blow-off cock should be provided with every boiler to draw off water from it when necessary to empty the boiler. In practice it is quite usual to connect the blow-off pipe direct to the drainage system, either to the kitchen sink trap or to the waste pipe below the sink trap. This is bad practice. When a building is closed for any great period of time, the boiler is usually drained of water and the blow-off cock left open to carry off any drip from the pipes or boiler. That provides a direct communication between the house drainage system and the water supply system and possibly the living rooms.

The best place to discharge the water from the blow-off of a boiler is in a trapped and water-supplied sink when there is one at a lower level than the boiler blow-off. When there is not, a compression hose bibb connected to a branch of the circulation pipe to the waterback will provide a means of emptying the boiler through a hose or into pails. The blow-off cock should always be located at the lowest part of the water heating apparatus, so it can be completely

drained of water. If the waterback is located on one floor and the boiler at a higher level, then the blow-off cock would have to be connected near the waterback.

DOUBLE HEATER CONNECTIONS TO BOILERS.—Two or more heaters are sometimes connected to one boiler. For instance, a coal or gas heater is sometimes used to heat the water during summer months, and a steam coil used to heat the water during winter weather. Each connection would be made independently of the other under such circumstances, and either means or both means could be used together to heat the water.

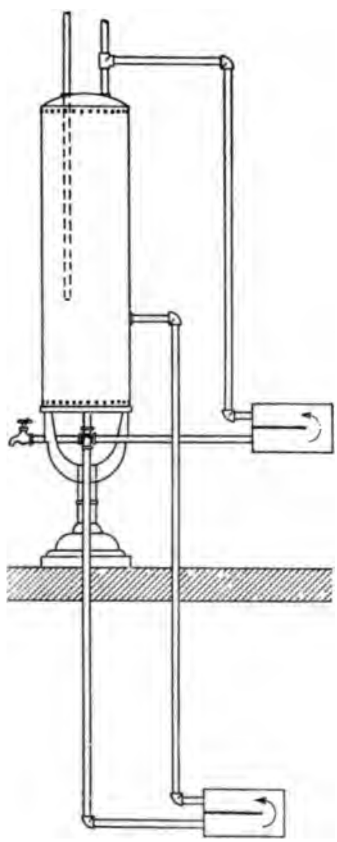


Fig. 134
Two Heater Connections to Boiler

The real test of the efficiency of a double heater connection to a boiler is the ability to heat with one or both heaters together. When two waterbacks or heaters are connected to the one hot water tank, by joining the flow and return pipe from both circuits, great care must be taken to connect them in such a manner that the current from one circuit will not be stronger than the current to the other circuit, and thus short circuit the strong current and shut off the flow from the weak one. That is what usually happens when one heater is located at a lower level than the other heater, or if located at the same level but at a great distance. Also, it might happen if one circuit was made of smaller pipe than the other one, or for any other cause was subject to greater friction.

The best way to connect two or more heaters to one

tank is to connect each one separately. If there are only two heaters they may be connected as shown in Fig. 134, or the flow connection can be reversed, so the flow pipe from the heater on the lower floor will enter the top of the boiler. This will not affect the circulation from either heater otherwise than to cause a loss of velocity in the upper circuit, due to loss of head. If more than two heaters are to be connected, special tappings should be provided in the tank for the extra flow and circulation pipes.

When two heaters are located at different levels they are sometimes connected so the water will pass in circuit through both of the waterbacks. This, however, is a poor method of connecting them. When a fire is burning in only one heater, a great amount of heat is lost by radiation in passing through the cold heater and extra circulation piping, and when there is a fire in both heaters the heat imparted to the water in the tank is less than if each heater was connected separately to the tank.

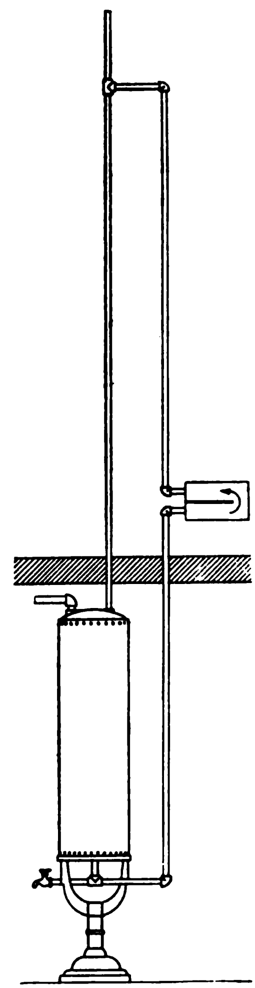


Fig. 135
Heater Connected to Boiler at Lower Level

HEATER CONNECTION TO BOILER AT LOWER LEVEL.—Circulation can be secured and the water heated in a boiler that is located below the level of the waterback, as shown in Fig. 135. When the boiler is so located, however, the circulation is sluggish at all times, and the weights of the two columns of water so nearly balance each other that good circulation cannot always be depended upon. Better results will be obtained by suspending the boiler in a horizontal position close to the cellar

ceiling, and extending the top loop at least twice the height of the lower loop or portion of the circuit. Also make the top or horizontal portion of the upper loop two sizes larger than the flow and return pipes, and as long as possible. In connecting the waterback to the boiler under such conditions, the circulation pipe from the boiler to the waterback is taken from the bottom of the boiler, and the flow pipe from the waterback to the boiler is extended vertically from the waterback to a distance equal to the distance from the waterback to the bottom of the boiler. If greater vertical height can be given to flow pipe, the more positive will be the circulation. The circulation pipe returns from the highest point to which it is carried and enters the top of the boiler. The hot water pipe is taken from the top of the circulation loop or a separate connection from boiler.

CONNECTIONS TO HORIZONTAL BOILERS.—Boilers are sometimes placed in horizontal position when there is no floor space to set them vertically. The usual tapping for a vertical boiler may be used when set horizontally, but the better practice is to have special tappings. When a vertical boiler is placed horizontally and stock tappings used, a boiler tube should be placed in the hot water pipe and curved upward inside of the boiler so as to offer an outlet near the top of the boiler for the hot water. The side tapping of the boiler is turned down and used for the circulation opening to the waterback. The flow pipe from the waterback enters what would be the bottom tapping of the boiler and the cold water enters the cold water tapping without a tube. The only special tapping necessary for a horizontally placed boiler is on the top side, to provide a connection for the hot water pipe.

OVERHEATED WATER.—As previously stated, the relation between the boiling point of water (which also is the generating point of steam) and pressure is absolute. Under a given pressure water will boil and steam will generate at a certain temperature. Increase the pressure and the point at which the water will boil will also increase. Thus, at atmospheric pressure, water will boil at 212 degrees Fahrenheit, while if the pressure is increased to 50 pounds,

a common pressure for water in city mains, the boiling point of the water will be increased to 297 degrees Fahrenheit.

If water under pressure is raised to a temperature above 212 degrees Fahrenheit and then released to the atmosphere, part of the water will instantly flash into steam and continue to generate steam until the temperature of the water is reduced below the boiling point at atmospheric pressure. Thus, when water under pressure in a tank is raised to the boiling point at that pressure and a hot water faucet is opened, steam will flow from the faucet with a sputtering sound caused by the mixture of water with the steam. This flow of steam will continue until the temperature of the water in the tank has been lowered by the inflowing cold water to below 212 degrees Fahrenheit. The hot water tank is not full of steam, as would appear to the person at the faucet, but the water is instantly converted into steam as soon as the pressure is released from the water at the faucet. The overheating of water in a tank can be prevented by the use of temperature regulators, which are made to control the supply of steam to steam coil, also to regulate the drafts to water heaters,

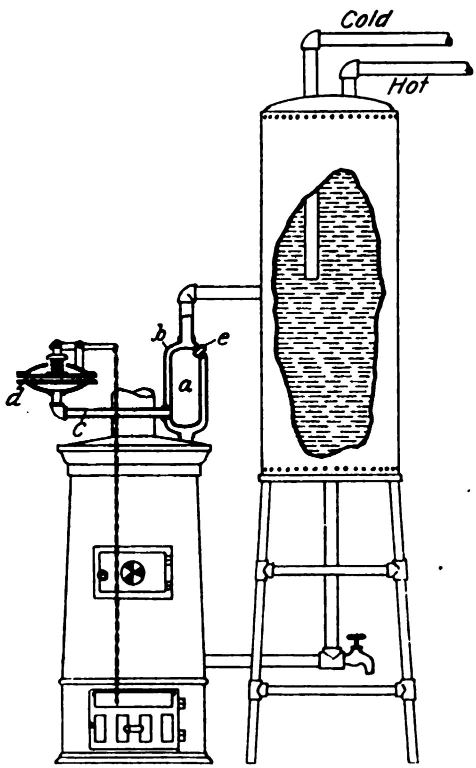


Fig. 136
Draft Regulator

and by these means maintain a uniform temperature of water in a tank.

DRAFT REGULATORS.—An apparatus used to regulate the drafts of a water heater is shown in Fig. 136. It consists of a chamber, *a*, enclosed in a casting, *b*, with an annular space between them for water to circulate through. The inner chamber is connected by means of a pipe, *c*, to a diaphragm in valve, *d*, which it fitted with a lever and chain, so that any movement of the lever will open or close the dampers. The regulator is attached to the flow pipe from a heater, as shown in the illustration. The operation of the apparatus is as follows: The inner chamber is partly filled with water through the plugged connection, *e*, and the plug screwed in to prevent the escape of water or steam. The water in the inner chamber is under atmospheric pressure, which boils at 212 degrees Fahrenheit, while the water in the heater is under an additional pressure that prevents it boiling at the same temperature as that in the chamber; hence, when the temperature of the water in the heater rises above 212 degrees Fahrenheit it will cause the water in the chamber to generate steam, which presses the water against the diaphragm of the valve, *d*, thereby depressing the lever and closing the dampers. The fire is at once checked and no steam can form in the hot water tank, as the boiling point for the corresponding pressure has not been reached. When the temperature of the water in the heater falls below 212 degrees Fahrenheit the steam in the chamber condenses and pressure is released from the diaphragm, which immediately settles back into place, thus opening the dampers.

STEAM COIL REGULATORS.—A regulator used for controlling the supply of steam to heating coils in tanks is shown in Fig. 137. It is operated by means of the unequal expansion of two different metal bars, *a*, which when heated to a certain temperature by water in the tank, *b*, open a small valve, *c*, in a water supply pipe, thus admitting the water pressure to the diaphragm valve, *d*. The pressure of water on the diaphragm closes the valve and thus cuts off the supply of steam from the coil. As soon as the tempera-

ture of water in the tank falls sufficiently, the metal bars contract, thus shutting off the supply of water from the diaphragm valve, which is opened by a spring and again admits steam to the coil.

CIRCULATION PIPES.—Hot water pipes that are extended any great distance to a fixture or group of fixtures should be provided with a circulation pipe through which hot water can circulate and thus be close to the faucets at all times. If circulation pipes are not provided, the water in hot water pipes cools when not being constantly drawn, and much time is wasted emptying the pipes of cold water when hot water is wanted. The water annually wasted in this manner, in any building would more than pay for circulation pipes.

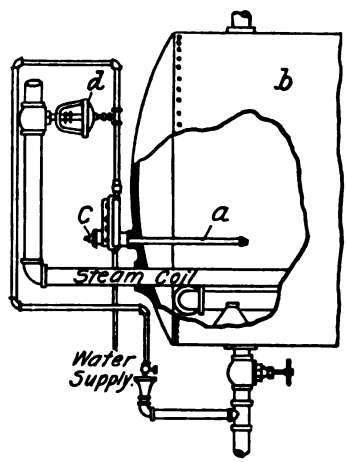


Fig. 137
Steam Coil Regulator

When installing the hot water system, a return pipe of smaller diameter than the hot water pipe is carried from the highest point of the hot water riser back to the boiler, where it may be connected to a separate tapping in the boiler or it may be connected to the return pipe from boiler to waterback. A valve should be put in each return pipe in a position to correspond with the shut-off valve in a hot water pipe, and both should be opened or closed as the case may be. Should only the hot water valve be closed, water would back up through the circulation pipe, and should the return valve be closed there would be no circulation through the pipes.

A hot-water pipe should rise from the boiler connection to the highest point in the system, then return to the bottom connection of the boiler or to where it is connected to the apparatus. If the hot-water pipe should dip below its grade, should be trapped, or pitch down instead of up, the system would not work, and there would be no circulation.

The return pipe from the highest part of the circulation system may be trapped or dip below the level of the boiler, as, for instance, should it be necessary to carry the return to the boiler in the basement or cellar, and this will not interfere with the circulation of water. **The hot-water** pipe, however, must have a positive rise from the boiler to the highest point in the system.

Gravity circulation cannot be maintained in long, low buildings without the aid of a circulating pump. If the length of the building is not too great, circulation can be maintained by rising direct from the boiler to the top of the building, along the ceiling of the top floor to the end of the run, down to supply the groups of fixtures, and back to the boiler along the cellar ceiling.

EXPANSION OF PIPES.—Water pipes expand or contract for every change of temperature to which they are subjected. To provide for this, in all tall buildings expansion loops are placed in both hot water and circulation pipe to permit the expansion and contraction of the lines without injury to the pipes. The loops are usually from 6 to 8 feet long, made as shown in Fig. 138, placed under floors and spaced about 50 feet apart. Usually hot water and circulation pipes are fastened midway between loops and allowed to expand both up and down. Long horizontal runs should likewise have expansion loops or room to expand. The length that water pipes will expand depends upon the degree to which they are heated and the material of the pipes. Within ordinary ranges of temperature, cast iron pipe varies $\frac{1}{162000}$ of its length for each degree Fahrenheit, heated or cooled. Wrought iron pipe varies $\frac{1}{150000}$ of its length for each degree Fahrenheit heated or cooled, and brass pipe varies $\frac{1}{100000}$ of its length for each degree Fahrenheit heated or cooled. Hence the expansion or con-

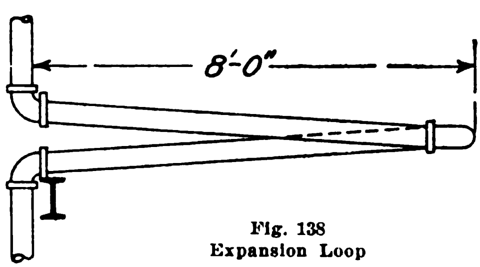


Fig. 138
Expansion Loop

traction of any pipe, when the length and the temperature of water are known, can be found by the following rule:

Rule—Multiply the length of pipe in inches by the number of degrees Fahrenheit it is heated or cooled, and divide the product by the coefficient of expansion for the kind of pipe used.

Expressed as a formula:

$e = \frac{l\,h}{c}$. When l = length of pipe in inches, h = degrees Fahr. the pipe is heated or cooled, c = coefficient of expansion ($\frac{1}{162000}$ cast iron, $\frac{1}{150000}$ wrought iron and $\frac{1}{100000}$ brass), e = elongation of pipe in inches.

EXAMPLE—What will be the expansion of a wrought iron pipe 100 feet long when heated from 60 to 212 degrees temperature?

SOLUTION—100 ft. $\times$ 12 in. $\times$ 152 = 182400 $\div$ 150000 = 1.21 inches.

In Tables LXXXIII, LXXXIV and LXXXV the linear expansion of cast iron, wrought iron and brass pipe for each 100 feet length at different temperatures is given.

TABLE LXXXIII. Expansion of Cast Iron Pipe

Temperature of Air when Pipe is Fitted	Length of Pipe when Fitted	Length of Pipe when heated to							
		215 Deg. Fahr. Atmospheric Pressure		265 Deg. Fahr. 15 Pounds Pressure		297 Deg. Fahr. 84 Pounds Pressure		338 Deg. Fahr. 100 Pounds Pressure	
Deg. Fahr.	Feet	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
0	100	100	1.59	100	1.96	100	2.20	100	2.50
32	100	100	1.36	100	1.65	100	1.96	100	2.27
64	100	100	1.12	100	1.43	100	1.73	100	2.00

TABLE LXXXIV. Expansion of Wrought Pipe

Temperature of Air when Pipe is Fitted	Length of Pipe when Fitted	Length of Pipe when heated to							
		215 Deg. Fahr. Atmospheric Pressure		265 Deg. Fahr. 15 Pounds Pressure		297 Deg. Fahr. 84 Pounds Pressure		338 Deg. Fahr. 100 Pounds Pressure	
Deg. Fahr.	Feet	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
0	100	100	1.72	100	2.21	100	2.31	100	2.70
32	100	100	1.47	100	1.78	100	2.12	100	2.45
64	100	100	1.21	110	1.68	100	1.87	100	2.19

PIPE COVERINGS.—Hot water pipes and hot water tanks that are uncovered lose by radiation from their surface about 13 B. T. U. per minute per square foot of surface.

TABLE LXXXV. Expansion of Brass Pipe

Tempera-ture of Air when Pipe is Fitted	Length of Pipe when Fitted	Length of Pipe when heated to							
		215 Deg. Fahr. Atmospheric Pressure		265 Deg. Fahr. 15 Pounds Pressure		297 Deg. Fahr. 84 Pounds Pressure		338 Deg. Fahr. 100 Pounds Pressure	
Deg. Fahr.	Feet	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
0	100	100	2.58	100	3.18	100	3.56	100	4.05
32	100	100	2.19	100	2.79	100	3.18	100	3.67
64	100	100	1.81	100	2.41	100	2.79	100	3.28

To prevent this loss of heat and consequent extra consumption of coal, hot water pipes, circulation pipes, and hot water tanks in large installations are usually covered with some non-heat conducting substance.

TABLE LXXXVI. Values of Pipe Coverings

Name	Maker	B. T. U. loss per sq. ft. pipe surface per minute.	Per cent. or ratio of loss to loss from bare pipe.	Thickness in inches.	Weight in ounces per ft. of length, 4 in. diameter.
Nonpareil Cork Standard	Nonpareil Cork Co.	2.20	15.9	1.00	27
Nonpareil Cork Octagonal	Nonpareil Cork Co.	2.38	17.2	.80	16
Manville High Pressure	Manville Covering Co.	2.38	17.2	1.25	54
Magnesia	Keasby & Mattison Co.	2.45	17.7	1.12	35
Imperial Asbestos	H. F. Watson	2.49	18.0	1.12	45
"W. B."	H. F. Watson	2.62	18.9	1.12	59
Asbestos Air Cell	Asbestos Paper Co.	2.77	20.0	1.12	35
Manville Infusorial Earth	Manville Covering Co.	2.80	20.2	1.50	..
Manville Low Pressure	Manville Covering Co.	2.87	20.7	1.25	..
Manville Magnesia Asbestos	Manville Covering Co.	2.88	20.8	1.50	65
Magnabestos	Keasby & Mattison Co.	2.91	21.0	1.12	48
Moulded Sectional	H. F. Watson	3.00	21.7	1.12	41
Asbestos Fire Board	Asbestos Paper Co.	3.33	24.1	1.12	35
Calcite	Philip Carey Co.	3.61	26.1	1.12	66
Bare Pipe	......	13.84	100.0	......	......

The relative values of different makes of pipe coverings, as determined by tests conducted by Charles L. Norton, of the Massachusetts Institute of Technology, for the Mutual Boiler Insurance Co., of Boston, can be found in Table LXXXVI.

Carbonate of magnesia is a very poor conductor of heat, therefore, it is a good material for covering hot water pipes. The name "Magnesia," however, is often applied to pipe coverings made of carbonate of lime, or of plaster of paris. Table LXXXVII shows the percentage of lime and magnesia found by C. L. Norton in several well-known brands of "Magnesia" coverings.

TABLE LXXXVII. Lime and Magnesia in Pipe Coverings

Name	Percentage Composition	
	$Mg. CO_3$ Carbonate of Magnesia	$Ca. SO_4$ Sulphate of Calcium
K. & M. Magnesia	80 to 90	3
Manville H. P. Lining	Less than 5	65 to 75
Watson Moulded	20 to 25	50 to 60
Carey Calcite	Less than 5	75
Manville Magnesia Asbestos	10 to 15	None

Data on pipe covering from Circular No. 6 of the Mutual Boiler Insurance Company, of Boston.

Mineral wool, which was always considered a good covering, was not reported upon by the above experimenter, for the reason that mineral wool is of no value as a heat retardant.

"Under vibration it is apt to become more and more massed into a semi-solid, leaving the top of a pipe partially covered, the under side of the covering more and more solid and therefore less effective. It is a dangerous material to handle and to use. The fine dust getting under the nails creates irritation and sometimes bad sores, or, passing into the bronchial tubes and the lungs, sometimes causes hemorrhage."

The conclusions to which we have been led by the tests on which report is now made, are as follows:

There are a sufficient number of safe, suitable and incombustible coverings for steam pipes and boilers to maintain a reasonable and adequate competition, without giving regard to any of the composite pipe coverings which contain combustible material in greater or less quantity, according to the integrity of the makers, and without giving regard to pipe coverings which contain substances like the sulphate of lime, which may cause the dangerous corrosion of the metal against which it is placed. We therefore name as the pipe and boiler coverings which may have the preference in respect to safety from fire and efficiency in service, the following makes:

Name	Made by
Nonpareil Cork................	Nonpareil Cork Co., Bridgeport, Conn.
Magnesia	Keasby & Mattison Co., Ambler, Pa.
Asbestos Air Cell.............	Asbestos Paper Co., Boston.
Imperial Asbestos	H. F. Watson Co., Erie, Pa

Hair felt and wool felt when new are good heat retardants, but deteriorate with age, and besides furnish a breeding place for house bugs and vermin.

The value of pipe coverings is not proportional to its thickness. Sectional pipe coverings average about 1⅜ inches in thickness and reduce the loss by radiation about 90 per cent., doubling the thickness of pipe covering only saves about another 5 per cent. of heat loss. In specifying covering for pipes and boilers, therefore, a thickness of 1⅜ inches will be sufficient.

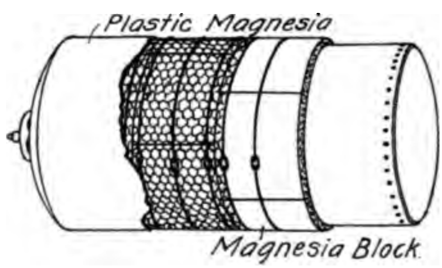


Fig. 139
Covering for Hot Water Tank

COVERING FOR TANKS.—On account of the objectionable appearance they would present, range boilers are seldom covered to prevent loss of heat by radiation. Hot water tanks, however, are usually located in the basement or cellar, where appearance

is of less importance than the prevention of loss of heat, therefore they should be covered with about 1⅜ inches of some good non-heat conducting covering. Tanks are generally covered with plastic asbestos troweled over a band of expanded metal, or asbestos blocks, Fig. 139, held in place by a wire netting.

CHAPTER XXIX

ICE-WATER SUPPLY

COOLING TANKS.—The cooling of water for drinking purposes begins at the cooling tanks, which must be rightly proportioned and properly built if the best and most economical results are to be obtained. Cooling tanks are nothing more or less than ordinary ice boxes, and any well-made ice chest can be used for the purpose, although on account of the hard usage received, it is well to have cooling tanks made of extra strength.

Tightness and heat insulation are the two prime requisites of the ice box. The box may be made water-tight by lining it with sheet metal of some kind, or by placing inside of the ice chest a specially built galvanized steel tank. So far as efficiency is concerned, either will answer, although the steel tank will wear the better.

The ice chest must be well insulated with from four to six inches of charcoal, granulated cork or some equally good non-heat conducting substance, and fitted with good covers, either single or double.

Where only one drinking fountain is to be installed, or where the fountains are widely scattered, individual ice boxes for each fountain will prove the most satisfactory and economical. When, however, there are a number of drinking fountains grouped fairly close together, one ice box centrally located will be found the most satisfactory.

An ice box suitable for this purpose is shown in Fig. 140. It will be noted that the ice in this box rests on a perforated platform above the ice coils. This prevents the coils from being damaged when putting ice in the chest, and, as the ice does not come in contact with the coils, necessitates retaining water in the tank. This is far from being a disadvantage, however, for the water from melted ice is cold enough to cool the drinking water to the right degree, and will absorb enough heat from the drinking water to make it economically advisable to use the water for cooling

purposes. For instance, the following data about water in an ice cooler of this description will prove the point:

Temperature of water at surface in contact with ice.....	41° F.
Temperature of water at bottom of ice box..............	43° F.
Temperature of water drawn at basement fountain.......	53° F.
Temperature of water drawn at first floor fountain.......	53° F.
Temperature of water drawn at second floor fountain.....	53° F.
Temperature of water drawn at third floor fountain......	53° F.

Accepting the average temperature of the water in the ice chest as 42 degrees Fahrenheit, then it is only about ten degrees warmer than the temperature of the ice, and that ten degrees heat, or the greater portion of it no doubt, was absorbed from the drinking water passing through the coils.

The waste and overflow connections are so arranged that water can be retained in the ice box up to the level of the overflow, and the water then overflowing is from the bottom of the ice box, where the warmest water will be found, or, by opening the valve in the waste pipe, the water will drain out as fast as the ice melts.

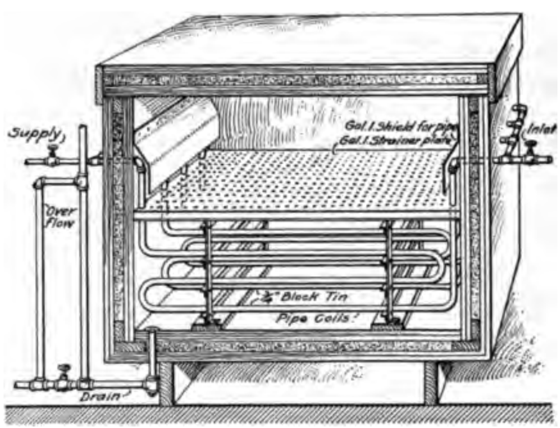


Fig. 140
Cooling Tank for Ice Water Supply

In proportioning the ice box, about three cubic feet of space should be allowed for each drinking fountain to be served. Indeed, it would be well to allow slightly more space to take care of the ice needed in extremely hot weather, then the cooling of water can be regulated in ordinary weather by not using so much ice. The amount of ice required will of course depend upon the weather. Ordinar-

ily, 50 pounds of ice per day for each fountain will be found sufficient, although in excessively hot weather it might require over three times that amount.

COOLING COILS.—In the foregoing illustration, the pipe coil is shown occupying the main part of the tank. This is not necessary, however, and other methods are often resorted to. For instance, a flat coil may be laid on the bottom of the ice tank, or wall coils, may be run around the sides of the tank thereby keeping them out of the way of the ice, so they will not be damaged when putting the ice in the box, and at the same time permitting a smaller size of tank to be used.

When a bottom coil is used, it is well to fasten over the coil a rack or grating of heavy timbers, say 2½ x 5, to keep the ice from coming in contact with the coils and possibly damaging them.

SIZE AND MATERIAL OF COOLING COILS.—For ordinary service, 10 feet of ¾-inch pipe will be a sufficient allowance for each drinking fountain supplied. That would be the equivalent of about 2¼ square feet of surface, the inside surface of the pipe being taken, as that is the surface to which heat is applied; fourteen feet of ½-inch pipe; eight feet of 1-inch pipe; 6¼ lineal feet of 1¼-inch pipe, or 5½ feet of 1½-inch pipe.

Water stands in the cooling coils sometimes for a long while, so it is undesirable to use lead pipe or common iron pipe for this purpose. Brass pipe, copper pipe, block-tin pipe or Benedict Nickel Steel pipe will be found best for this purpose.

DISTRIBUTION OF ICE-WATER.—Cold water cannot be satisfactorily circulated without the aid of a pump. The attempt has been made to secure a circulation by gravity, by locating the ice box in the attic, and depending on the heating of the water in the down supply upsetting the balance of the two columns of water enough to cause an up circulation in the return pipe. The difference in temperature is so slight, however, and the friction of the pipe proportionally so great, that it will not circulate. Even if it did, there are practical objections to such a system of ice-water supply.

In the first place, there is the muss and fuss of carrying the ice to the attic, and in the second place, the attic being the hottest part of the building, and so much hotter than the cellar where it would naturally be located, that much more ice would have to be used to keep the water at the required temperature.

WATER COOLER FOR OUT-DOOR FOUNTAIN.—For factories spread over large areas, parks, public playgrounds and like places, a sanitary drinking fountain supplied with cooled water can be fitted up as shown in Fig. 141. Experience has shown that a brick or concrete vault 2 feet wide, 2½ feet long and 3½ feet deep, containing a little over 17 cubic feet of space, and capable of holding from 700 to 800 pounds of ice, will keep the water cool for 24 hours and in sufficient quantity to supply 3000 people.

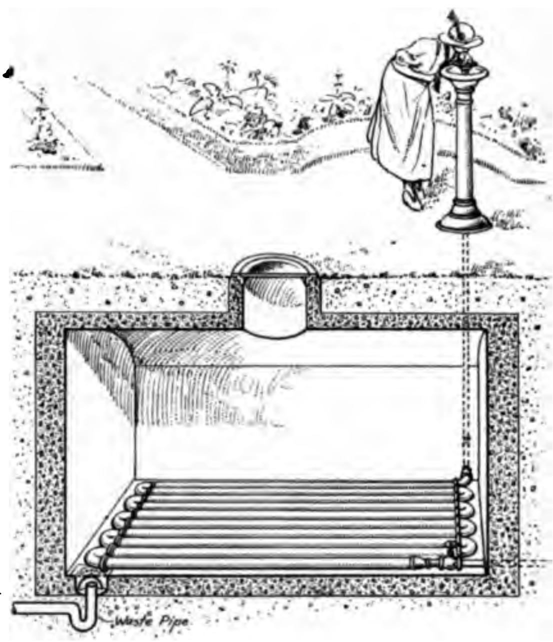


Fig. 141
Water Cooler for Outdoor Fountain

About 9 square feet of coil surface, or 21 lineal feet of 1½-inch pipe will be found sufficient for ordinary locations; but, where the flow is almost continuous, 14 to 15 square feet of pipe surface will be needed to keep the water cooled to the right temperature.

WATER-COOLING REFRIGERATING MACHINES.—Mechanical refrigeration is now generally used for cooling the drink-

ing water for large office buildings, hotels, clubs and like buildings. This requires a miniature plant of its own, or an expansion or brine coil from the general system, when refrigeration for other purposes is required in the building.

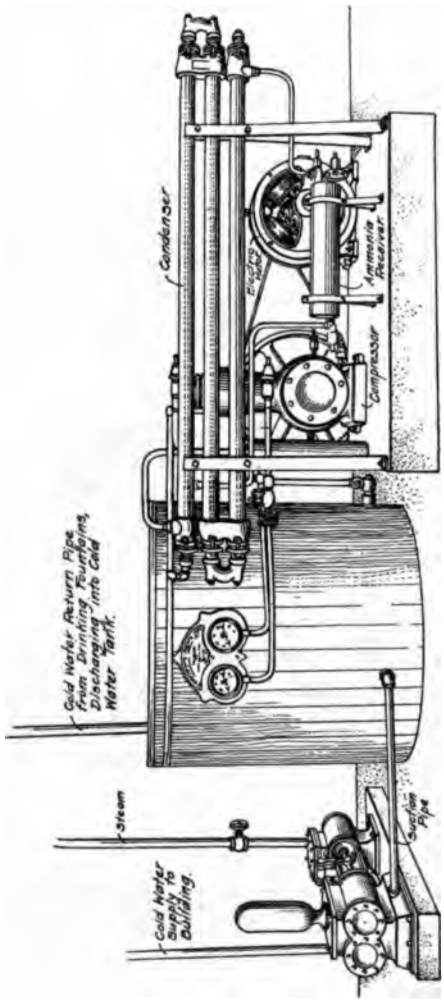


Fig. 142
Ice Water Cachine

The complete refrigerating system for a water-cooling plant is shown in Fig. 142. This was designed with a capacity of from twenty-five to thirty drinking fountains, and is operated by an electric motor. In supplying ice

water to a building a pump is necessary to keep up a circulation through the supply pipes, so that cold water will be on tap the moment a faucet is opened. If the water were not kept in circulation, it would soon grow warm, and considerable water would have to be drawn before cold water could be obtained. From the circulating pump the risers are taken to the attic, or 10 or 12 feet above the level of the highest fixture, if there are none on the top floor, then returned and discharged into the cooling tank. In some cases a small tank called a "balancing tank" is provided in the attic, and the water from the risers discharge into this, the overflow being carried back to the cooling tank in the cellar or basement. Supply branches to the drinking fountains are taken off the up-risers, so there will always be a supply available, and under a suitable head or pressure.

It is very necessary to insulate thoroughly the ice-water pipes or they will condense the moisture in the atmosphere, thereby "sweating" and being a nuisance generally.

In proportioning the system, an allowance of about 3 gallons capacity in the cold water tank for each fountain to be supplied, will be right for ordinary service.

ACTUAL PERFORMANCE OF REFRIGERATING MACHINE.—In the 30-story Union Central Office Building, Cincinnati, Ohio, a 10-ton Frick machine furnishes the tenants with ice water. Steam pressure 80 pounds; back-pressure on condenser 15 pounds, and condenser pressure 150 pounds. City water is taken in at a temperature of 75 degrees Fahrenheit and cooled to an average of 44 degrees at the fountains throughout the building, of which there are 50 between the basement and the twenty-eighth floor. There were 468 pounds of steam used by the ice machine per hour, or 3,744 during the eight-hour test, which required 430 pounds of coal.

CHAPTER XXX

WATER SUPPLY FOR SUBURBAN PLACES

WINDMILLS.—One of the cheapest and most satisfactory ways of pumping water for domestic or irrigation purposes is by means of windmills. There are two types of windmills in use, distinguished by the materials used in making the sails of the wind wheel. One is the windmill with the sails of the windwheel made of narrow strips of wood set at a steep angle. Such windmills run at slow speed and operate the pump direct from the crank, and are called "direct-stroke" windmills. The other type has curved steel sails set at a flat angle in the windwheel. These wheels revolve at high speed, and the high speed of the windwheel is geared down to the proper speed for operating the pump. These windmills are known as "back-geared" windmills. Both types of windmills have certain features adapting them to different requirements.

ACTION OF WIND ON WINDMILLS.—It requires at least an 8-mile wind to do any effective work with a windmill, and they will not operate to the best advantage in winds of over 25 miles an hour. Very few windmills are made with larger wheels than 30 feet in diameter, and they are regulated to govern at a velocity of 25 miles an hour. There are no pumps or attachments which will enable the user of a windmill to utilize the increased power obtained from winds of high velocity, so that in practice the amount of water pumped by windmills in high winds is but little more than is pumped by the same mills in winds having velocities of from 12 to 18 miles an hour. The velocity of wind, pressure per square foot on the sails and action of the wind on a windmill, can be seen in Table LXXXVIII.

From the table it will be seen that the only available winds are those blowing with a velocity of from 8 to 25 miles per hour, and that a 15-mile wind can be utilized to the best advantage. It is best, therefore, to "load" a windmill for a 15-mile wind. It will then start pumping in an

8-mile wind, do excellent work in a 15-mile wind, and reach the maximum results in a 25-mile wind. It will be further observed that a wind velocity of 15 miles per hour develops a power three times as great as an 8-mile wind; and a 20-mile wind is twice as powerful as a 15-mile, or six times that of an 8-mile wind. It naturally follows that a small increase in velocity greatly increases the power of windmills, while a low velocity gives but a low working force.

TABLE LXXXVIII. Action of Wind on Windmills

Velocity of Wind in Miles per Hour	Pressure per Square Foot in Pounds	Description of Wind	Action of Wind on Windmill
3	.045	Just perceptible.....	Windmill will not run
5	.125	Pleasant wind......	Might start if lightly loaded
8	.33	Fresh breeze.......	Will start pump
10	.5	Average wind......	Pumps nicely if properly loaded
15	1.125	Good working wind..	Does excellent work
20	2.	Strong wind........	Gives best service
25	3.125	Very strong wind...	Maximum results secured
30	4.5	Gale..............	Should be furled out of work
40	8.	Storm.............	Well constructed mills and towers are safe if properly erected
50	12.5	Severe Storm.......	
60	18.	Violent Storm......	Buildings, trees, etc., might be damaged
80	32.	Hurricane..........	Buildings, trees, etc., would be damaged
100	50.	Tornado...........	Ruin

The capacities of windmills based on the size of wheel, velocity of wind, and revolutions of wheel per minute, can be found in Table LXXXIX. This table gives also the amount of water that can be raised to different heights or elevations.

AVERAGE VELOCITY OF WIND.—Windmills would be of but little use if there was not enough wind blowing to operate them. As a matter of fact, at some time during every twenty-four hours, there is enough wind blowing to operate a windmill and pump water. The average velocity of wind throughout the entire United States is very nearly 8 miles per hour, while for large areas, such as the great plains east of the Rocky Mountains, the average is about 11 miles

per hour. Again, in certain small areas situated in mountainous districts, the average velocity is as low as 5 miles per hour; therefore, in selecting and loading a windmill, the wind velocity prevailing in the particular locality where it will be used must be considered. In such localities the mills should be loaded to operate in 10-mile winds, instead of 15-mile wind recommended for general use. A mill loaded for a 10-mile wind can be depended upon to furnish a sufficient supply of water in those localities where the average wind velocity is low.

TABLE LXXXIX. Capacity of Windmills

Diam. of Wheel of Mill.	Velocity of Wind in Miles per Hour.	Revolutions of Wheel per Minute.	Gallons of Water Raised per Minute to an Elevation of						Equivalent to Actual Useful Horsepower.
			25 Feet	50 Feet	75 Feet	100 Feet	150 Feet	200 Feet	
8½	16	40 to 50	6.192	3.016					0.04
10	16	35 to 40	19.179	9.563	6.638	4.750			0.12
12	16	30 to 35	33.941	17.952	11.851	8.435	5.680		0.21
14	16	28 to 35	45.139	22.569	15.304	11.246	7.807	4.998	0.28
16	16	25 to 30	64.600	31.654	19.540	16.150	9.771	8.075	0.41
18	16	22 to 25	97.682	52.165	32.513	24.421	17.485	12.211	0.61
20	16	20 to 22	124.950	63.750	40.800	31.248	19.284	15.938	0.78
25	16	16 to 18	212.381	106.964	71.604	49.725	37.349	26.741	1.34

Pumping windmills have their windwheels designed and proportioned for the speed at which the pump can be properly operated. Pumps in wells up to 100 feet deep are operated at about 35 or 40 strokes per minute. Pumps in wells from 100 to 200 feet deep are operated at from 25 to 30 strokes per minute; and in wells from 200 to 400 feet deep, the pumps should not be operated faster than 15 to 20 strokes per minute. Pumps for deep wells must be set directly over the well. If a suction pump is to be used, on the other hand, it can be set at any convenient point so long as it is not too far above the level of the water supply.

WOODEN STORAGE TANKS.—Cylindrical wooden tanks for the storage of water should be made of white cedar, cypress, white or red pine, Douglas or Washington fir, or

air-dried redwood. The lumber must be free from sap, loose or unsound knots, worm holes and shakes, and be thoroughly air-dried. Tanks of the best white cedar and those of good cypress are about equally durable. They will last at least 15 years, and commonly from 20 to 25 years. The following specifications for storage tanks, abstracted from the requirements of the fire underwriters, gives the best practice in tank design. The staves and bottoms for tanks not exceeding in diameter 16 feet, nor more than 16 feet deep, must be made of 2½-inch stock dressed on both sides to a thickness of 2¼ inches. For larger tanks 3-inch stock dressed on both sides to 2¾ inches must be used, and for tanks smaller than 16 feet, 2-inch stock may be used.

The hoops must be round in cross section.

The strength of a tank depends chiefly on its hoops. Experience shows that flat hoops, especially those of steel, rust from the back side where they bear against the staves, and serious accidents have happened by hoops bursting on account of this unobserved corrosion. Sometimes galvanizing or painting is depended upon to prevent rusting, but there is always the possibility that spots of the protective coating will be knocked off in handling, and one spot left unprotected may result in the failure of the hoop. Round hoops are, therefore, advised for all tanks, since for a given cross section of metal, these hoops have the advantage of presenting the least surface to corrosion. Nearly the whole surface can, moreover, be examined or painted while the hoops are in place. In setting up a tank with round hoops there is little probability of tightening the hoops to such an extent that when the tank swells the hoops will burst; for the round hoops will simply indent the wood more as the tank swells and the stress in the hoops is not likely to be increased to the breaking point if reasonable care is used.

The hoops must be made of wrought iron or mild steel of good quality. Wrought iron is preferable, however, because it is more rust resisting. The wrought iron must have a tensile strength of at least 50,000 pounds per square inch. Steel must have a tensile strength not less than 55,000 to 60,000 pounds per square inch and the percentage

of carbon must not exceed 0.10. There must be no welds in the hoops. Where more than one length of iron is necessary, lugs similar to Fig. 143 must be used to make the connection. Cast iron lugs not malleableized are not acceptable, as they are liable to crack.

Hoops with "upset" ends are not allowed because: first the metal is likely to be burned in upsetting unless done under careful supervision; and, second, the additional diameter is likely to be gained by welding bolt ends to smaller rods, thus introducing a weak place in the weld.

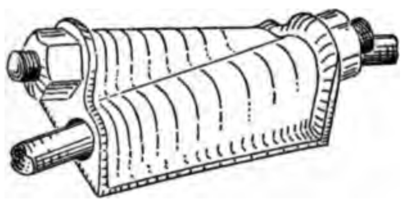


Fig. 143
Lug for Hoops

When the screw threads are cut directly on the end of a hoop, the unthreaded portion may be corroded to a depth equal to the depth of the threads without weakening the hoop. The screw thread itself is not so liable to serious corrosion as the portion of the hoop which bears against the staves, since the latter is subjected to moisture from the wood.

TABLE XC. Strength of Wooden Tank Hoops

Diameter of Round Rod in Inches	Area of Section of Rod in Square Inches	Net Area at Root of Thread in Square Inches	Safe Working Load in Pounds
¾	.44	.30	3,750
⅞	.60	.42	5,250
1	.79	.55	6,875
1⅛	.99	.69	8,625

The hoops must be of such size and spacing that the stress will not exceed 12,500 pounds per square inch when computed from area at root of thread. Hoops must not be less than ¾ inch diameter. Table XC gives proper working strength for hoops of sizes commonly used, based on this allowable stress.

The top hoop must be placed within two inches of the top of staves. No space between hoops to exceed 21 inches. The hoops must be so placed that lugs will not come in a vertical line. The spacing of hoops can be found from the following diagram, Fig. 144.

The following example will best show the use of the

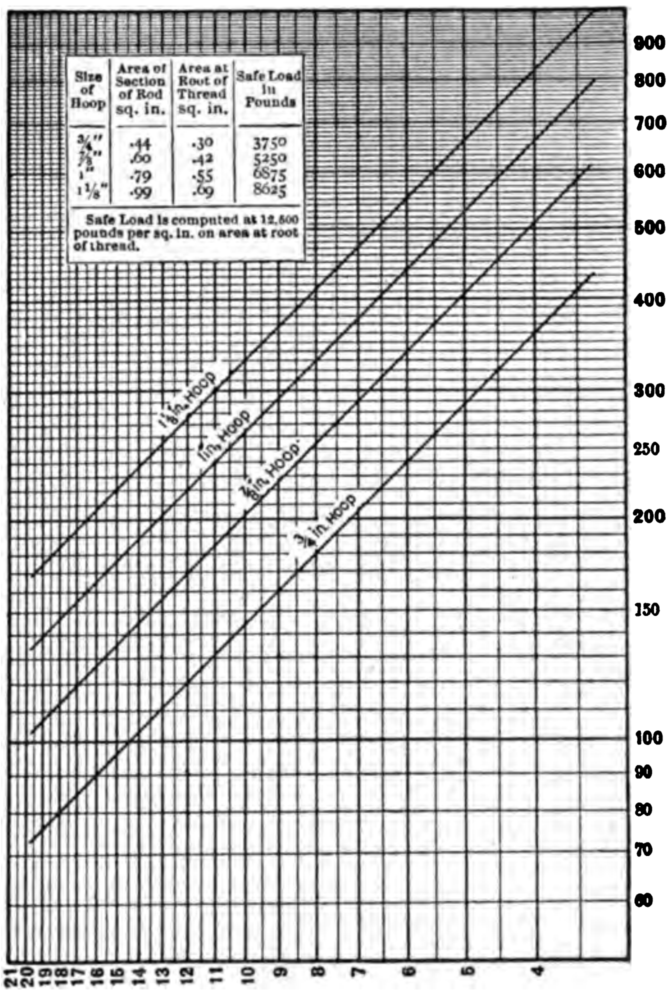


Fig. 144
Showing Allowable Spacing for Hoops

diagram: How far apart should 1-inch hoops be placed, at 15 feet from the top, on a tank 20 feet diameter?

$15 \times 20 = 300$. Follow up the right side of the diagram where marked "Product of diameter (feet) $\times$ depth (feet)" till you come to 300; then follow the horizontal line to the left till it intersects the diagonal line marked "1-inch Hoop;" then follow downward to the bottom of the diagram, and it will be seen that the hoops under conditions above stated may be spaced $8\frac{3}{4}$ inches apart.

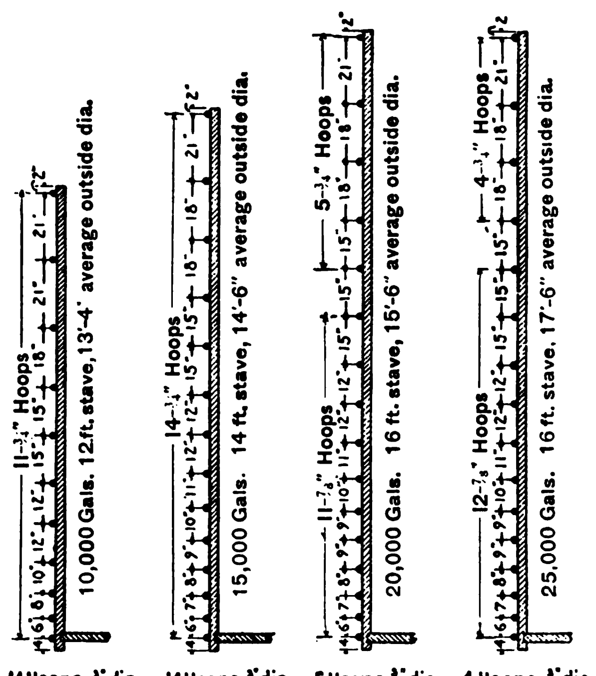


Fig. 145
Proper Spacing of Hoops

In a similar way the spacing for any hoop for any size tank may be found.

Extra hoops must be provided near the bottom to take the additional load due to the swelling of the bottom planks. For tanks up to 20 feet in diameter, one hoop of the size

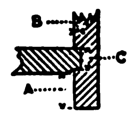
used next above it must be placed around the bottom opposite the croze. For tanks 20 feet or more in diameter two hoops must be used as above.

The hoop or hoops at the croze are to be counted upon as taking the water pressure of half the space above.

The spacing of hoops on tanks is shown graphically for several different sizes of tanks in Fig. 145.

DIMENSIONS FOR TANKS OF STANDARD SIZES.—For convenience Table XCI, giving dimensions for a few tanks of certain sizes, is added.

TABLE XCI. Dimensions of Wooden Tanks



Approx. Net Capacity	SIZE (Outside Dimensions)		Thickness of Lumber after being Machined					HOOPS	
Gals.	Average Diam. Ft.-In.	Length of Stave Ft.	Staves In.	Bot'm In.	A In.	B In.	C In.	No. of	Size In.
10,000	13-4	12	2¼	2¼	3½	⅝	2⅛	11	¾
15,000	14-6	14	2¼	2¼	3½	⅝	2⅛	14	¾
20,000	15-6	16	2¼	2¼	3½	⅝	2⅛	5 11	¾ ⅞
25,000	17-6	16	2¾	2¾	3½	¾	2⅝	4 12	¾ ⅞
30,000	18-0	18	2¾	2¾	3½	¾	2⅝	4 16	¾ ⅞
40,000	19-6	20	2¾	2¾	3½	¾	2⅝	3 10 11	¾ ⅞ 1
50,000	22-0	20	2¾	2¾	3½	¾	2⅝	4 19	⅞ 1

The number and size of hoops are stated and the spacing for same are shown in Fig. 145. The proper size and spacing of hoops for tanks of other dimensions can readily be computed by use of the diagram.

Tanks located outdoors must be covered with a double roof, an acceptable construction being shown in plan in Fig. 146, and in elevation in Fig. 147. It must consist of a tight flat cover made of matched boards supported by joists,

and above this a conical roof. In the larger sizes the conical roof must be supported by rafters extending from the top of the tank to the peak of the roof.

The conical roof must be covered with galvanized sheet iron or a good composition roofing which is not readily ignitible.

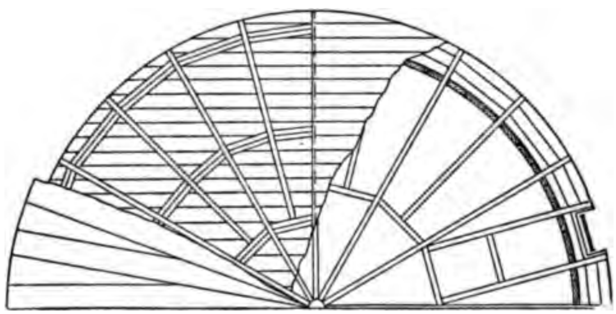


Fig. 146
Plan of Tank Roof

EXPANSION JOINT.—When a tank is supported by a tower 30 feet or more in height, whether on the ground or on a building, an expansion joint of the approved type shown in Fig. 148 must be provided in the discharge pipe at

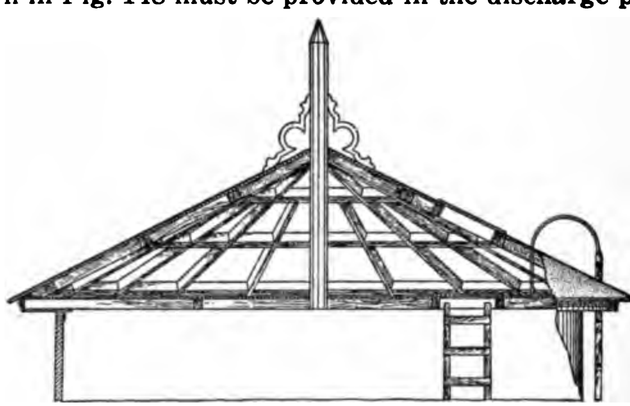


Fig. 147
Double Cover for Tank

the tank connection. In those cases where a tank is located in a brick or reinforced concrete tower, a four-elbow swing joint may be used.

OVERFLOW PIPE.—The overflow pipe must be 2 inches in diameter for tanks up to 30,000 gallons capacity and 3 inches in diameter for larger tanks.

A short length of 2-inch pipe will discharge about 100 gallons per minute when the surface of the water is three inches above the centre of the pipe.

The top of the overflow pipe must be placed 3 inches below the top of the staves of a wooden tank and 1 inch below the top of the cylindrical shell of a steel tank.

The overflow pipe must extend through the bottom or side of tank. In the latter case it must project beyond the balcony.

FROST-PROOFING FOR PIPES. — The discharge and hot water or steam pipes, and separate filling pipe when one is needed, for a tank on a tower on the ground or roof of a building, must be protected from freezing by a frost-proof covering in addition to having the water in the discharge pipe heated.

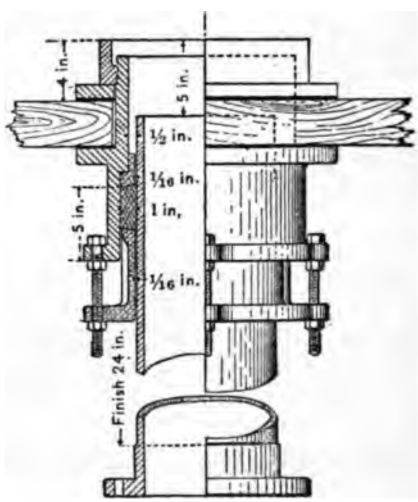


Fig. 148
Expansion Joint for Wooden Tanks

The frost-proof covering should not be depended upon to prevent freezing of the pipes without some heat being added. Most tanks for fire protective purposes have no draft from them except in case of fire, therefore the water in the discharge pipes has little or no circulation. For this reason, these pipes need more thorough protection than do pipes in similar positions which discharge from tanks in which there is nearly constant circulation, as for example in a village supply. Therefore the amount of protection to be provided for a certain pipe must be decided with due regard to the severity of exposure to

cold winter winds, frequency of circulation in the pipe and amount of heat to be supplied.

The standard frost-proof boxings are made of wood and are circular as shown in Fig. 149, or square in section as shown in Fig. 150.

The boxings may be made more durable by using stock which has been antiseptically treated.

A good tight joint must be made between boxing and bottom of tank. The lower end of boxing must be supported by the sides of the pit, which must extend about a foot above ground. The woodwork must be well painted.

Sheet lead or tarred paper should be placed between bottom of boxing and the pit to avoid absorption of moisture.

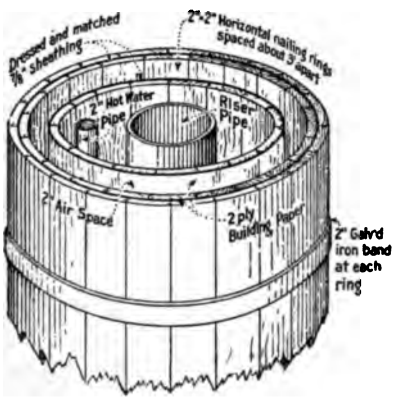


Fig. 149
Circular Frost-Proof Boxing

The upper part of boxing must be constructed so as to permit of access to the **expansion** joint without the necessity of destroying any portion of the boxing.

The boxing must be made four-ply, with two air spaces, for tanks in northern Canada. It must be three-ply, with two air spaces, as shown in Figs. 149 and 150, for tanks in New England, New York, Ontario, Michigan and Wisconsin. Two-ply boxing with two air spaces must be used in States immediately south of this section. This boxing may also be used in the Southern States or else the pipes may be wrapped with felt and tar paper and covered with canvas.

Calculating Wind Stresses in a Four-Post Tower

The following is one method of computing the stresses due to the wind. The problem involves a simple application of graphic statics, and depends upon the proposition that a force is fully determined when its magnitude, direction and point of application are known. Such a force may be

represented by a line, and the stress diagram in its simplest form represents the force as sides of a polygon taken in order. The closing side in reverse order is the resultant in magnitude and direction. The diagram shown in Fig. 151 is a typical one and the method of computation is as follows:

1 represents one bent of a 100-foot tower supporting a 40,000-gallon tank. The loadings beginning at the top of the diagram are 4,330 pounds, applied at centre of gravity of the projected surface of tank and roof; 1,750 pounds, which is equal to 100 pounds per foot or ½ the height of the top stage; 3,500 pounds, which is equal to 100 pounds per foot for ½ the heights of the top and middle stages; and

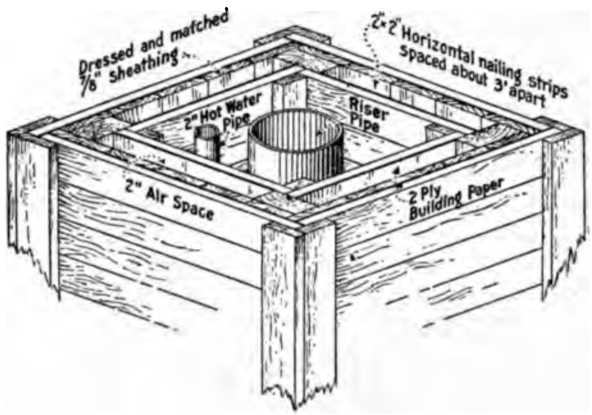


Fig. 150
Square Frost-Proof Boxing

3,700 pounds, which is equal to 100 pounds per foot for ½ the heights of middle and bottom stages. One-half the wind load is used because one bent is being considered.

2 shows the stress diagram and, as it is drawn to scale, the force resulting may be measured directly from it.

3 is a plan-view of 1 and shows the wind blowing in the plane of one bent. This being the case the axis of rotation will be through *xx* and posts *r* and *s* will take compression, while posts *o* and *p* will take tension. The amount of the compression in post *o* has been found from the diagram to be 39600 pounds. The uplift or tension in the anchor bolt at the foot of post *p* will be a like amount. Sup-

pose, however, we consider the wind blowing in some other direction and determine which is the worst case for wind loading.

4 shows the same plan-view with the wind blowing in a diagonal direction, as indicated by arrow. The axis of rotation will be through *xx*, and this being the case post *r*

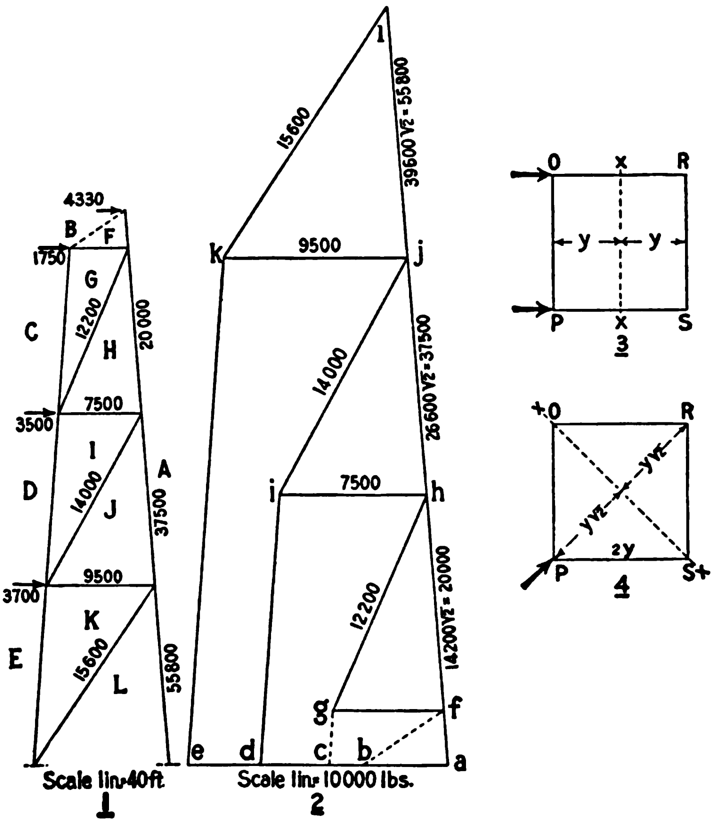


Fig. 151
Diagram of Wind Pressures

will take all the compression. The relative amounts of the compression in these two axes are shown to be as follows:

In 3 let *m* represent the total overturning moment, then the compression in *r* and *s* is equal to $\frac{M}{4y}$ while in 4 the compression in *r* equals $\frac{M}{2yV^2} - \frac{MV^2}{4y}$

In other words the compression in *r* in 4 is the same as the compression in either *r* or *s*, in 3, times $\sqrt{2}$ therefore the maximum compression due to the load may be taken as the amount scaled from the stress diagram multiplied by the $\sqrt{2}$

Similarly the maximum tension in any set of anchor bolts will be equal to the maximum compression in the leeward post in 3 less one-fourth the total weight of the structure and tank.

The stresses in the diagonal rods and struts are considered to be the maximum when the wind is blowing as in 3, and therefore may be scaled directly from the diagram.

HYDRAULIC RAMS.—The hydraulic ram is an engine for pumping water, using the force stored up in a moving column of water to cause a shock or water hammer, which will take water from one level and raise it to a higher elevation. By means of a ram, water at a low head may be used to raise a portion of the same or some other water to a level higher than the supply. These efficient engines will pump water 30 feet high for every foot of fall. They will operate with as little as 2 feet fall, or with a head of 30 feet, and will deliver water to a height of 500 feet and to a distance of 2½ miles. Finally, they may be had in sizes which will deliver from 1500 gallons a day to 1,000,000 gallons in 24 hours.

A Rife Hydraulic Engine is shown in Fig. 152. This contains only two working parts, the waste valve and the supply valve, so that once the engine is set up and started, it will continue to work successfully until some parts of the valves wear so they need repair. They cost nothing for operating expenses, and are about on a par with windmills in point of economy for operating.

Rife hydraulic engines are made in two types. One is the single-acting engine which elevates part of the water used for operating the ram, and the other is a double-acting engine, which pumps a pure water, using a supply of inferior water to operate the ram. The principles of operation of these two types can be seen in Fig. 153, which shows the operating parts of the engine. In the single-acting ram

the pipe marked *h-i* is omitted, and the operation of the engine is as follows:

The valve at *b* being open, the water from the source of supply at more or less elevation above the machine flows down the drive-pipe *a*, and escapes through the opening at *b*, until the pressure due to the increasing velocity of the water is sufficient to close the valve *b*. At the moment when the flow through this valve ceases, the inertia of the moving column of water produces the so-called ramming stroke, which opens the valve at *c*, and compresses the air in the air chamber *d*, until the pressure of the air plus the pressure due to the head of the water in the main, is sufficient to overcome the inertia of the moving column of water in the drive-pipe. This motion may be likened to the oscillations in a U-tube. At this instant the column of water in the drive-pipe has come to a rest, and the air pressure being greater than the static head alone, the direction of motion of the moving column is reversed and the valve, *c*, closed. The water in the drive-pipe is then moving backward, and with the closing of *c* a tendency to a vacuum is produced at the base of the drive-

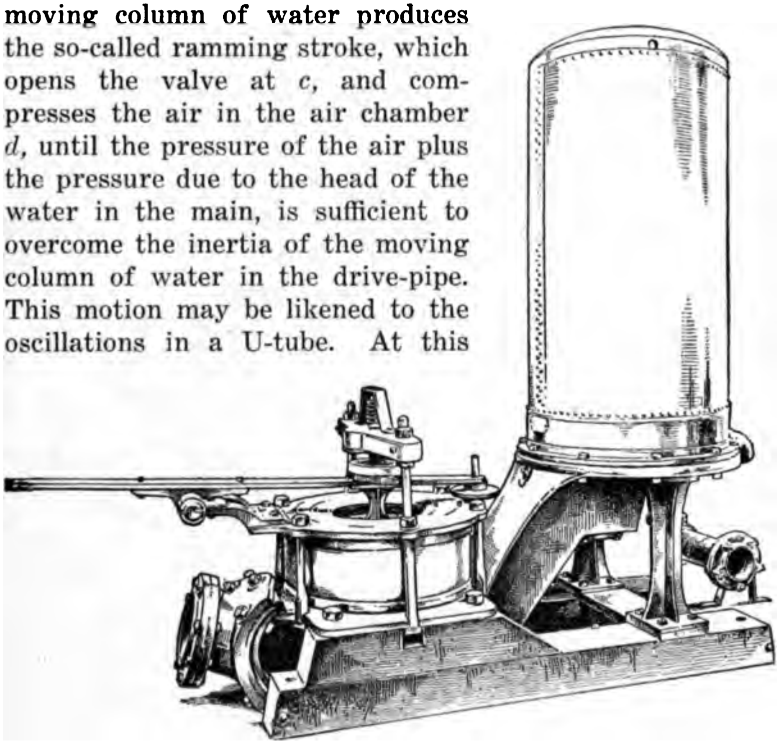


Fig. 152
Rife Hydraulic Engine

pipe; this negative pressure causes the valve *b*, to open again, completing the cycle of operations. At the moment of negative pressure the little snifting valve, *e*, admits a small quantity of air, and at the following stroke this passes into the air chamber, which would otherwise gradually fill with water, the air being gradually taken up by water.

In many machines the mistake is made of making the waste-valve, *b*, sufficiently heavy to overcome the static head of water in the drive-pipe. In fact, most writers on this subject, including the "*Encyclopedia Britannica,*" state that the weight of the waste valve, *b*, must be greater than the

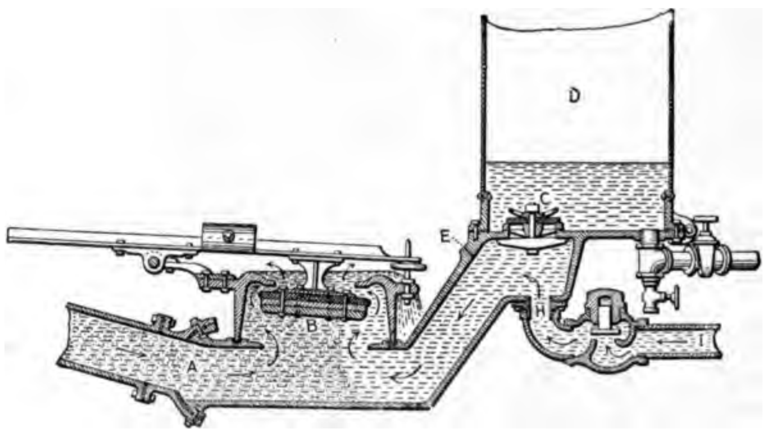


Fig. 153
Section of Rife Hydraulic Ram for Pumping Water, Using Impure Water for Power

pressure of the statical head of water on its under side so that it may open when the column of water comes to rest. In the machine which we are describing this would be practically impossible on account of the large area of the opening at *b*.

In this machine the valve, *b*, is made as light as is consistent with the necessary strength; the negative pressure at the end of the stroke is relied upon to open the valve.

When an impure water is to be used to drive the ram and deliver a pure water, the pipe, *h-i*, is attached to the ram as shown in the illustration, and the spring water is delivered to the ram through this pipe. The engine is then

double-acting, and by a proper adjustment of the relative flow of the impure driving water and the pure spring water, the engine may be made to deliver only pure water to the supply tank. This method is used only where the supply of pure water is limited, and there is a plentiful supply of the driving water. To deliver pure water, using impure water as power, there must be at least 18 to 24 inches of fall from the spring stand-pipe to the engine. If there is a greater natural fall, it must be piped to a tank having an overflow 24 inches above the supply pipe, *h-i*, so there will not be a greater head than two feet to the pure water. The engine should be set on a firm, level foundation, but need not be fastened.

TABLE XCII. Sizes of Rife Rams

Number	Dimensions			Size of Drive-Pipe	Size of Delivery-Pipe	Gallons per Minute Required to Operate Engine	Least Feet of Fall Recommended	Weight
	Height	Length	Width					
10	2′ 1″	3′ 2″	1′ 8″	1¼″	¾″	3 to 6	3	150
15	2′ 1″	3′ 4″	1′ 8″	1½″	¾″	5 to 12	3	175
*20	2′ 3″	3′ 8″	1′ 9″	2″	1″	10 to 18	2	252
25	2′ 3″	3′ 9″	1′ 9″	2½″	1″	11 to 24	2	250
30	2′ 7″	3′10″	1′10″	3″	1¼″	15 to 35	2	275
40	3′ 3″	4′ 4″	2′ 0″	4″	2″	30 to 75	2	600
80	7′ 4″	8′ 4″	2′ 8″	8″	4″	150 to 350	2	2500
*120				12″	5″	375 to 750	2	3000
†120	8′ 9″	9′ 6″	3′ 8″	2-12″	6″	750 to 1500	2	5500

*Single. †Duplex.

DRIVE-PIPE FOR RAM.—The length of drive pipe is governed by the ratio of fall or driving head to elevation or pumping head. If the drive pipe is either too long or too short, the automatic supply of air will be interfered with and the efficiency of the engine impaired. The drive pipe must be laid in a perfectly straight line, without bends or curves, except where the pipe enters the engine, and this should be made by bending the pipe. The upper end of the drive pipe where it takes in water ought to be far enough

below the surface so it will not take in air. It should be submerged one foot or more, and the entrance protected by a good open strainer. The delivery pipe can be laid with the necessary fittings, according to the usual practice with water pipes.

In Table XCII can be found the size of drive pipe, dimensions and quantity of water required to operate different sizes of Rife Rams.

In Table XCIII can be found the sizes of Gould rams and the length of drive pipes to operate them. These lengths may be accepted as approximations for usual conditions.

TABLE XCIII. Conditions and Sizes* of Gould Rams

To Deliver Water to Height of	Place Ram under	Conducted through
20 ft. above Ram	3 ft. Head of Fall	30 ft. of Drive Pipe
30 ft. above Ram	4 ft. Head of Fall	30 ft. of Drive Pipe
40 ft. above Ram	5 ft. Head of Fall	40 ft. of Drive Pipe
50 ft. above Ram	7 ft. Head of Fall	50 ft. of Drive Pipe
60 ft. above Ram	8 ft. Head of Fall	60 ft. of Drive Pipe
80 ft. above Ram	10 ft. Head of Fall	80 ft. of Drive Pipe
100 ft. above Ram	14 ft. Head of Fall	100 ft. of Drive Pipe
120 ft. above Ram	17 ft. Head of Fall	125 ft. of Drive Pipe

*Any size Ram may be operated under these conditions and will afford the following approximate delivery:

No. 2 requires	2 to 3 gals. per minute	and delivers	10 to 15 gals. per hour
No. 3 requires	2 to 4 gals. per minute	and delivers	10 to 20 gals. per hour
No. 4 requires	3 to 7 gals. per minute	and delivers	15 to 35 gals. per hour
No. 5 requires	6 to 12 gals. per minute	and delivers	30 to 60 gals. per hour
No. 6 requires	11 to 20 gals. per minute	and delivers	65 to 100 gals. per hour
No. 7 requires	18 to 35 gals. per minute	and delivers	90 to 175 gals. per hour
No. 8 requires	30 to 60 gals. per minute	and delivers	150 to 300 gals. per hour

EFFICIENCY AND CAPACITY OF RAMS.—The question of efficiency of hydraulic rams has been much discussed, and such authorities as Rankine and D'Aubisson differ considerably in their calculations. Rankine's formula is:

$$E = \frac{q\,h}{(Q-q)\,H},$$

where Q is the quantity of water flowing per second in the

drive-pipe; q, the quantity flowing per second to the stand-pipe through the discharge pipe; H, the height from the escape valve to the level of the reservoir which feeds the drive-pipe; and h, the difference in the level of the water-supply reservoir and the water in the stand-pipe. D'Aubisson states the formula for efficiency as

$$E = \frac{q\,(H + h)}{Q\,H}$$

D'Aubisson's is the correct one, considering the mechanism as a machine receiving energy at one end and delivering it at the other, while if the machine is considered as elevating water only from the one reservoir to the other, Rankine's formula is the correct one to use.

The capacities of Rife Rams can be found in Table XCIV.

The size of ram to use is easily determined by either of the two tables given. For instance, opposite each ram the maximum and minimum amount of water this ram will use will be found, and by simply multiplying either the maximum or minimum amounts the ram uses by the factors found in the table of capacities, will give either the minimum or maximum amount this particular ram will deliver. Take a No. 20 engine for example. This ram will use from 10 to 18 gallons a minute. Now, then, if it is found that 15 gallons of water is all that is available, then multiply that amount by the factor found in the table of efficiencies, which will give the amount of water that will be delivered.

The factors in the table are based on the ratio of power head or fall for the drive pipe, to the height the water must be elevated. This and the efficiency developed are shown in connection with the example worked out, in the corner of Table of Capacities. It will be noted that the number of gallons is 1400 per minute, which is multiplied by 192. Now, opposite 10 foot fall and under 50 elevation, this number 192 is found. This is a ratio of 5 to 1. In looking at the bottom of page giving the efficiencies, it will be found that the ratio from 1 to 3 up to 1 to 18 equals 66 2/3% efficiency, so that in determining the amount this ram will deliver, it was figured on 66 2/3% efficiency. A ram, if installed

TABLE XCIV. Capacity of Rife Rams

Power Head or Fall in Feet	Height or Head in Feet the Water is to be Delivered																
	4	10	15	20	30	40	*50	60	70	80	90	100	120	140	160	180	200
2	540	192	128	96	64	43	29	24									
3		301	192	144	96	72	58	43	37	27	24						
4		432	256	192	128	96	77	64	55	43	38	29	24				
5		540	345	240	160	120	96	80	69	60	53	43	30	26			
6			432	302	192	144	115	96	82	72	64	57	43	31	27	24	
7			505	378	235	168	134	112	96	84	75	67	50	36	31	28	25
8				432	270	192	154	128	110	96	86	77	64	55	43	38	29
9				485	300	216	173	144	124	108	96	86	72	62	54	43	39
*10				540	360	252	*192	160	137	120	107	96	80	68	60	53	43
12					430	301	230	192	165	144	128	115	96	82	72	64	57
14					505	353	270	224	192	168	150	135	112	96	84	75	67
16						432	323	257	220	192	171	154	128	110	96	85	77
18						486	390	303	247	216	192	173	144	124	108	96	86
20						540	430	336	288	240	214	192	160	137	120	107	96
22							475	370	303	264	235	212	176	151	132	118	105
24							520	405	346	288	256	230	192	164	144	128	115
26								470	375	328	278	250	208	178	156	139	125
28								505	430	354	300	269	224	192	168	149	134
30								540	465	405	336	288	240	206	180	160	144

EXAMPLE
With a supply of 1400 gallons per minute, 10 feet fall, 50 feet elevation, No. 120 engine will deliver 268,800 gallons per day. 1400 × 192 = 268,800

*Multiply factor opposite "power head" and under "pumping head" by the number of gallons per minute used by the engine and the result will be the number of gallons delivered per day.

Efficiency developed is governed by the ratio of fall to pumping head and

Efficiency of Rife rams based on
- 75% for a ratio of 1 to 2½
- 70% for a ratio of 1 to 3
- 66 2/3% for a ratio up to 1 to 18
- 60% for a ratio up to 1 to 23
- 50% for a ratio up to 1 to 30

under 3 foot fall and 75 foot elevation, which is a ratio of 1 to 25, the efficiency table shows that 50% efficiency would be developed where the ratio is 1 to 23 up to 1 to 30.

PNEUMATIC WATER SUPPLY.—The pneumatic system of water supply utilizes the compressibility of air to force water out of a tank to any required elevation. When water is pumped into an empty tank, the air already in the tank is trapped there and compressed in the upper part, the water occupying the lower part of the tank. All pipe connections are made near the bottom of the tank so the air cannot escape, then, when a faucet is opened, the compressed air within the tank forces the water out at the fixture.

The air in the tank would soon become exhausted, however, if more air were not supplied in proportion to the water pumped into the tank, and to keep up the supply of air a small air compressor, "snifter" valve, or some other equally positive device must be employed to pump air into the tank. The quantity of water that a tank will deliver at a given pressure and elevation depends on the proportion of air and water in the tank. If the air cushion is of small volume, the pressure drops so rapidly when water is drawn, that it becomes necessary to pump in more water, thus increasing the pressure by compressing the air into still smaller space. But this does not increase the volume of air.

The pressure of air in tanks when partly full of water, can be seen in Table XCV.

TABLE XCV. Proportions of Air and Water in Tanks

Amount of Water Pumped in Tank	If Tank Contained only Atmosphere, Pressure will be	If Tank is First Pumped to 10 Pounds Pressure with Air the Pressure will be
1/4 full of Water	5 Pounds	18 Pounds
2/5 full of Water	10 Pounds	26 Pounds
1/2 full of Water	15 Pounds	34 Pounds
3/5 full of Water	22 Pounds	47 Pounds
2/3 full of Water	29 Pounds	58 Pounds
3/4 full of Water	45 Pounds	83 Pounds

It will be noticed from the table of pressures that where

only the atmosphere in the tank is trapped and compressed, the volume of air is not sufficient to deliver under pressure all the water contained in the tank. For average requirements the best results are obtained when the proportion two-thirds water and one-third air is maintained. At this proportion the atmosphere in the tank will be compressed to a point where it will exert a pressure of 29 pounds per square inch.

Now, if water be further drawn off, until the pressure falls to 5 pounds, the tank will still be one-quarter full of water, and the pressure of air will not be sufficient to deliver it to any fixture higher than the tank itself, and that one-quarter tank of water will not be available. Had 10 pounds of air been pumped into the tank first, the pressure would be 58 pounds at the proportion of two-thirds water and one-third air, and this pressure would force practically all the water out of the tank, having a pressure of 18 pounds to force out the last quarter of water.

Another advantage of an initial air pressure of 10 pounds lies in the fact that a smaller tank can be used for a given installation. For instance, if a 750-gallon tank is first pumped to 10 pounds pressure with air, it will deliver as much water at equal pressure as would be available from a 1000-gallon tank without the additional air pressure.

CHAPTER XXXI

PLUMBING FIXTURES

Classification of Fixtures

PLUMBING FIXTURES.—Plumbing fixtures are here considered solely from a sanitary point of view. Types are discussed but not the various modifications or makes. Those may be seen in the show rooms of plumbing supply houses or very natural illustrations of them can be seen in plumbing supply catalogues.

Plumbing fixtures are receptacles for soil and waste water from which it is discharged into the drainage system. There are several classes of fixtures, each fixture being classified according to its use. Thus: Soil fixtures include water closets, urinals, school sinks, bidets, slop sinks, and all other fixtures into which soil is discharged. Scullery fixtures include kitchen sinks, pantry sinks, laundry tubs, and any fixture used in the preparation of meals or washing of household goods. Laving fixtures include wash basins, bath tubs, needle, shower and spray baths, and any fixture used for cleansing the person. Clean water fixtures like drinking fountains form a group by themselves.

REQUIREMENTS OF SANITARY FIXTURES.—To be perfectly sanitary, plumbing fixtures must be made of some non-absorbent, non-corrosive material that is not easily cracked, crazed or broken, and that has perfectly smooth surfaces to which soil will not adhere so firmly that it cannot be removed by a flush of water. Outlets of fixtures should be as large or larger than the waste pipe and should be unobstructed by strainers or cross-bars, so that the waste pipe will receive a scourging flush at each discharge of the fixture. Fixtures that are provided with stoppers for the waste outlet generally have overflows to prevent water overflowing the fixture when the stopper is in place. There is no reason why lavatories and bath tubs should have overflow channels, however. They seldom are of sufficient size to carry off the inflow of water, so they do not perform the

function for which intended. Often they leak when water rises to their level, and at all times they are unsatisfactory channels, which might well be dispensed with. Fixtures should be set open, that is, perfectly free from enclosing woodwork or other casings that would cut off light and air. They should be well supplied with water for flushing, and in public places the walls and floor where they are set should be lined with some non-absorbent material.

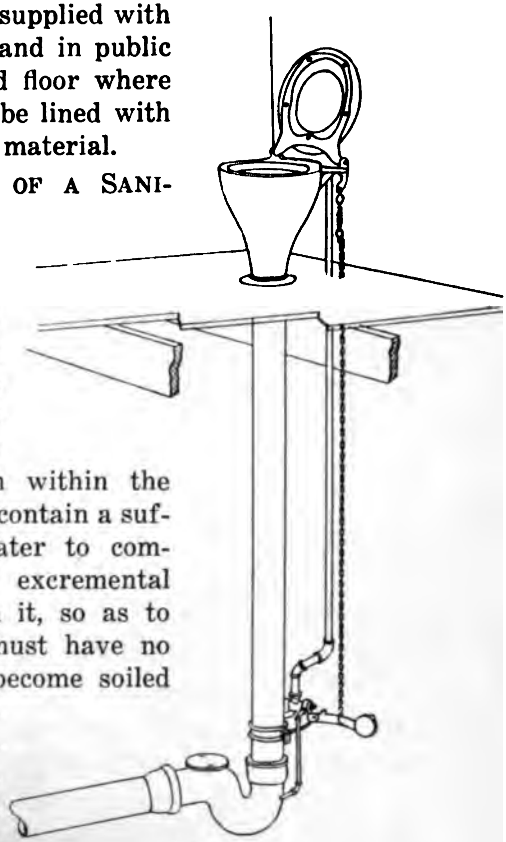


Fig. 154
Hopper Closet

REQUIREMENTS OF A SANITARY CLOSET.—To be efficient and sanitary, a water closet should be made of porcelain enameled iron or of vitreous ware, and must be absolutely free from working mechanism within the receptacle. It must contain a sufficient depth of water to completely cover any excremental matter deposited in it, so as to prevent odor. It must have no surfaces that can become soiled or that are not thoroughly water scoured every time the fixture is flushed. It must be supplied at each discharge with a sufficient volume of water to remove the entire contents of the bowl and trap and replace it with fresh water. The water should be discharged into the closet suddenly, with force, and in a large volume, and t[illegible]t must be connected to the soil pipe with a perfe[illegible] and permanently tight floor flange, that is flexi[illegible]d with shrinkage, settlement, and

other movement of the building. No closet can be sanitary which depends on a putty-joint for a seal.

HOPPER CLOSETS.—The simplest form of water closet is a hopper closet, shown in Fig. 154. It consists of a funnel or hopper-shaped bowl fitted with a flushing rim or pipe-wash connection. This type of closet contains no water in the bowl and the converging sides are dry and present the maximum surface to be soiled. Hopper closets are installed principally in exposed places where other types of closets that contain water would be damaged by the frost. When thus installed the closet trap and water supply valve are located in a pit below frost level, and after each flush of the fixture the water is automatically drained from the flush pipe down to the valve. When fitted up in this manner the entire inner surface of the pipe from the hopper to the trap, sometimes becomes covered with a coating of slime that in warm weather gives off a very disagreeable odor. At their best they are unsanitary and objectionable, and should not be permitted. Hopper closets located in warm places should be flushed from a tank or flush valve and should have the trap placed as close as possible to the closet bowl.

NUMBER OF FIXTURES REQUIRED.—The number of plumbing fixtures required depends somewhat on the type of building to be equipped. In Table XCVI will be found the number of fixtures of various kinds found sufficient to serve 100 patients in state hospitals for the insane in New York State.

TABLE XCVI. Plumbing Fixtures Required in Hospitals

Kind of Fixtures	Number required per 100 Patients	
	In Men's Ward	In Women's Ward
Water Closets	8	9
Urinals	4	0
Lavatories	10	9
Rain Baths	2	2
Bath Tubs	1	1

The number of toilet fixtures required in school buildings can be found in Table XCVII.

LAUNDRY FIXTURES AND CONNECTIONS.—The following list shows the fixtures installed in the laundry of the New York Ambassador, and the steam water waste and electric connections required:

No.	Kind of Machines	Connections
3	42x72" Washers	Hot and Cold Water, Steam and Electricity
2	42x36" No. 12 Washers	Hot and Cold Water, Steam and Electricity
3	40" Overbelt Driven Extractors	Connections for drain only, and electricity
1	28" Extractor	Connections for drain only, and electricity.
2	100 Gallon Soap Tanks	Cold Water and Steam Connections.
6	Wood Truck Tubs	None.
1	48x54" Clothes Tumbler	Electricity.
1	42x60" Hot Air Tumbler	Steam, Return with Trap and Electricity.
1	50 Gallon Starch Cooker	Steam only.
1	Zinc Covered Starch Table	Steam only
1	18" C. & C. Starcher	Steam, Return with Trap & Electricity.
1	3 loop 9' Conveyor Dryroom	Steam, Return with Trap & Electricity
1	No. 1 C. & C. Dampener	Electricity.
1	Heubsch Spray Dampener	Water and Steam.
1	Bishop Dampening Press	None.
2	30x120" Big Two Ironers	Steam, Return with Traps and Electricity.
1	66" Handy Type Ironer	Steam, Return with Trap and Electricity.
4	38" Troy-Prosperity Presses	Steam, Return with Trap
1	No. 361 Hagen-Keystone Bosom Press	Steam, Return with Trap and Electricity.
1	Type "C" Double Cuff Press	Steam, Return with Trap.
1	Type "C" Single Neckband Press	Steam and Return with Trap.
1	24" Steam C. & C. Ironer	Steam, Return with Trap and Electricity.
1	30x96" Finishing Table	None
1	No. 624 Shaw Collar Shaper	Electricity
1	Zeidler Improved Seam Dampener	Electricity
1	4¾" Porcelain Hot Tube Shaper	Steam Connections.
1	Shirt Ironing Table with outfit	Electricity for Iron.
8	Skirt Ironing Tables	Electricity for Irons.
9	No. 666 Gilbert Suspension Arms	Electricity.
9	No. 6 Electric Irons	Electricity
1	Box Curtain Dryer	Steam, Return with Trap.
1	3 Compartment Stationary Tub	Hot and Cold Water and Steam.
4	Flatwork Tables	None.

TABLE XCVII. Number of Toilet Fixtures for Schools

Number of Pupils	Kind and Number of Fixtures			
	Water Closets			Urinals
	Girls	Boys	Kindergarten	Boys
Under 30 Children....	2	1	2	2
50............	2	2	3	3
70............	4	2	3	4
100............	5	3	4	5
150............	6	3	5	7
200............	8	4	6	10
300............	12	5	8	15

SIPHON-ACTION CLOSETS.—The most satisfactory closets are those which operate on the siphon principle, and contain sufficiently large bodies of water in the bowls to submerge and deodorize anything discharged into them. In addition they ought to be so constructed that there will be no dry surfaces liable to foul or to which soil can adhere. The siphon-action closet shown in section in Fig. 155 is distinguished from all other types of siphon-acting closets by the horizontal portion of the outlet leg of the trap underneath the bowl. The trap instead of having a straight outlet, is more or less offset and curved as in all siphon-acting closets, so that water overflowing from the bowl will rarify the air to such an extent as to induce siphonic action to carry the contents from the bowl. There is considerable dry space above the water line in the bowl of this closet, and it is the least satisfactory of all the siphon-action types. Indeed, the diaphragm forming the upper part of the short leg of the trap

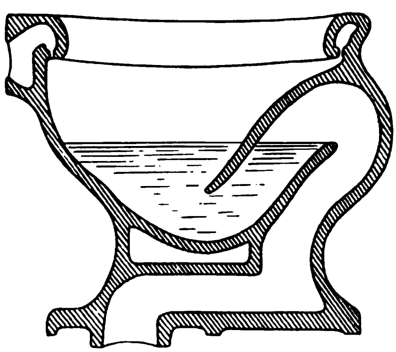


Fig. 155
Section of an Ordinary Siphon-Action Closet

in the bowl is so completely above the water, and so in the way, that it cannot escape being soiled more or less.

REVERSE-TRAP SIPHON-ACTION CLOSETS.—What is known as the reverse-trap siphon-action closet is shown in Fig. 156. The outlet leg of the trap in this type is quite similar to the outlet leg of the siphon-jet closet, which it resembles in general appearance. It is a better appearing and more satisfactory closet in every way than the ordinary siphon-action closets. As a rule they are smaller than the siphon-jet closet, contain less parts, and consequently cost less, while at the same time they rank a close second.

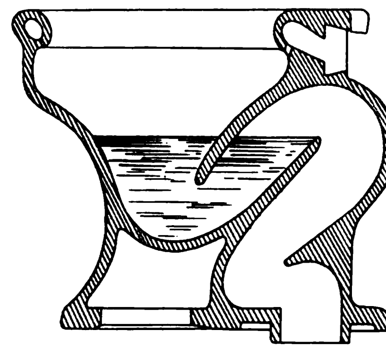


Fig. 156
Section of a Reverse Trap Siphon-Action Closet

SIPHON-JET CLOSETS.—A siphon-jet closet is shown in Fig. 157. This closet is vitreous, smooth, impervious and contains a large body of water in a receptacle so shaped that it cannot easily be soiled. In operation it is almost noiseless.

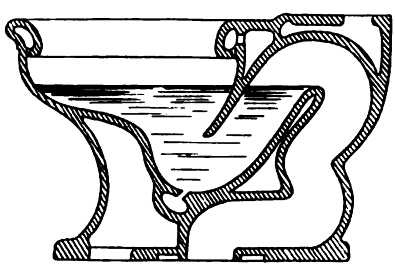


Fig. 157
Siphon-Jet Closet

The operation of a siphon-jet closet is as follows:

The flushing water parts upon entering the closet; some of it enters the flushing rim and cleanses the bowl, while the rest of it flows through the jet, and ejects the water from the closet. The ejected water enters the outlet leg of the closet, which is usually so constructed that the outlet can be easily filled with water or the air rarified. When the outlet leg becomes filled with water it acts as the long leg of a siphon, and thus siphons the contents of the bowl

into the soil pipe. Once the siphonic action is started it continues until the bowl is empty and enough air has entered the trap to prevent further siphonage. The closet is then refilled by the after-wash from the tank or flush valve.

As the contents of a siphon-jet closet are ejected by the pressure of the atmosphere on the surface of the water in the bowl, it follows that a considerable volume of air from in and around the closet will be carried into the soil pipe at each discharge, thus carrying off the most impure air from around the closet. Some siphon-action closets are now made with a jet, so it is hard to distinguish one type from the other. However, the siphon-action is smaller, and usually has a side flush connection, while the siphon-jet has a top connection.

One objection to the siphon-jet closet is the liability of shrinkage cracks or fire cracks which allow drain air to escape into the room. On account of the difficulty of manufacture, a large percentage of siphon-jet closets have this concealed defect.

Wall-hung closets are not siphon-acting. They are blow-out closets from which the contents are ejected or blown out by means of a jet of water. Closets are better installed resting on the floor than hung from wall or partition.

CLOSET FLOOR FLANGES.—No closet can be considered perfectly sanitary which depends upon a putty-joint, gasket or slip-joint for a seal. The one bad and weak spot in past practice has been the point where the water closet is connected to the soil pipe. Experience has shown that where a putty-joint, or a rigid gasket joint or slip-connection are used, the closet is either broken or the connection destroyed within a short time after the closet is installed. This is due to the settlements and shrinkages of the building, or the settlements, expansions and contractions of the drainage system.

The only sanitary connection for a water closet is a joint which is not only tight when it is put in, but will remain so during all the changes and movements which take place within the building. As many as 150 closets in

one building have been broken on account of rigid connections, and where the closets are not broken the floor joints are. Every closet connection, then, should be provided with a flexible fitting of some kind to protect the closets, and the floor flange itself is preferably of the metal-to-metal kind. It is obvious that this important connection should be as perfect as it is possible to make it. This can be assured only when the flange is made in the factory and tested before being sent out. A gasket connection is not a tight connection made so in the factory, but is merely the raw materials sent out for the plumber, if skillful enough, to make the joint tight. As it is almost an impossibility to make a tight joint using a rough gasket against a rough and irregular earthenware surface, the plumber falls back on putty or paste of some kind to make the joint tight, using it with the gasket, and to keep the joint tight until it has passed all tests. Such joints are not lasting, however, although they are fairly satisfactory when used in connection with a flexible fitting.

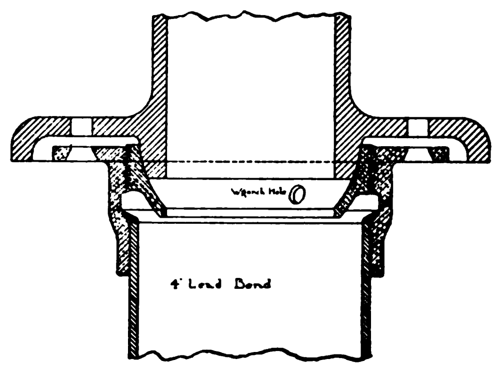


Fig. 158
Standard Ball Joint

The only sanitary types of flanges recognized as such are the metal-to-metal flanges. One flange of this type, known as the Standard Ball Joint, is shown in section in Fig. 158. This is what would be called a ground joint made on the well-known ball-and-socket principle. It is made tight in the factory, and when used in connection with a flexible fitting is one of the best closet floor flanges on the market.

Another metal-to-metal closet floor flange, known as the Pres-O-Flex, is shown in Fig. 159. This is a flexible connection, so constructed that it will stretch or collapse to

take care of any reasonable settlement, shrinkage, or other movement of the piping or building. This flange, like the Ball-joint, is made tight at the factory, and tested before being sent out, which ought to be required of any flange before specifying. If the maker is not willing to stand back of his goods for five years, the specifying architects cannot be expected to have much confidence in it.

FLUSH TANKS.—Water closets should always be flushed with water from flush tanks, or through specially constructed flush valves. There are two reasons for these requirements: First, the flush pipe or flush valve will be of

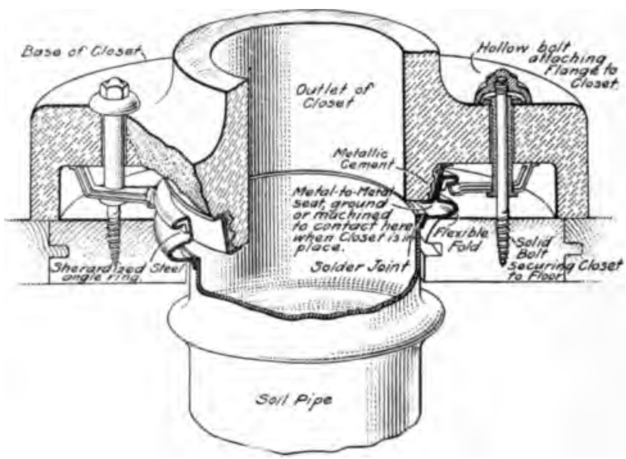


Fig. 159
Metal-to-Metal Floor Flange

sufficient size to supply a large volume of water in a short period of time, thus insuring a good flush; second, the tank can be proportioned or the flush valve regulated to furnish a certain quantity of water at each flush.

Flush tanks are made with capacities ranging from 6 to 12 gallons. In large city apartment houses, hotels and like buildings, where a considerable volume of water is generally flowing through the house drain, tanks of smaller capacity may be used than would be required in private houses or in large country institutions which are located a considerable distance from a trunk sewer or other place of

sewage disposal. The reason for this is that in large city buildings if a sufficient volume of water is provided in closet tank or flush valve to discharge the contents of a closet into the soil stack, it will fall by gravity to the house drain, where assisted by the flowing water in the drain, it will be carried to the street sewer. The functions of the flushing water is thereby performed and water economized at the same time. On the other hand, assistance from other sources cannot be depended upon in private buildings and country institutions, so a sufficient volume of water must be provided that will carry the contents of the closet bowl all the way to the street sewer. Closet tanks with siphon flush valves are generally used in connection with washdown, and hopper closets, while slow-closing flush valves are used with siphon-jet combinations.

FLUSH VALVES.—Flush valves are mechanically successful in operation, but are suitable only for buildings supplied with water from a storage tank. This does not mean they will not operate on direct city pressure, or that there is any sanitary reason for so installing them. The trouble lies in the large size of pipe required. If all the closets in a large city were served direct from the city mains through flush valves, the size of mains would be excessive.

Flush valves cannot be successfully used unless there is sufficient volume and pressure to operate them. For high-pressure service they require a head of at least twenty feet; where this head is unavailable, special low-pressure valves should be used.

Flush valves can be regulated to discharge almost any desired quantity of water at each flush of a fixture. The usual amounts vary from 4 to 8 gallons, which are discharged in from 3 to 6 seconds' time. If the service pipe is not large enough to supply this quantity of water within the required time a flush valve cannot be successfully used.

SIZE OF PIPES FOR FLUSH VALVES.—Care must be taken when installing flush valve systems to proportion the pipes so each valve will have an adequate supply of water. No pipe in the system should be smaller than 1 inch in diameter, and three to five closets is the greatest number a 1¼-inch

pipe will supply at the average pressure of 30 pounds. When there are more than four closets in an installation, a safe rule is to allow in the supply main the capacity of $\frac{3}{4}$-inch pipe for each closet. When the large battery of closets is at a place of public assemblage like a ball ground, the allowance should be midway between $\frac{3}{4}$ and 1 inch for each closet. When there are a greater number of closets than 100 in an office building, it can be assumed that all will not be operating at the same time and an allowance of the capacity of $\frac{3}{4}$-inch pipe be made for all the closets or of a 1-inch pipe for the greatest probable number that will be operated simultaneously.

EXAMPLE—What size of water main will be required to supply twenty-one flush valves?

SOLUTION—Required a pipe having the capacity of twenty-one $\frac{3}{4}$-inch pipes, and Table LI shows that a $2\frac{1}{2}$-inch pipe has a capacity of 23.3 $\frac{3}{4}$-inch pipes, therefore a $2\frac{1}{2}$-inch pipe should be used.

The sizes of pipes required for flush valves determined by the foregoing rule are based on the assumption that a main of adequate size is provided for the group, so the length of run from the main to the first flush valve will not be over twenty to forty feet, depending on the pressure, the range of pressure being from twenty to sixty pounds. If there is a long run of pipe from the source of supply to the group of closets to be served, the main must be proportioned to take care of the additional frictional resistance in the pipes. The capacity of a 1-inch pipe for each closet in the group will take care of the friction.

Table XCVIII gives the size of pipe required for a single flush valve installation, it being understood, of course, that as the number of water closets increases, the ratio of the size of pipes becomes smaller, due to the fact that the supply piping must only be large enough to take care of the maximum number of closets that are liable to be operated at one time.

SCHOOL SINKS AND LATRINE TROUGHS.—School sinks or latrines are sometimes installed in schools, barracks, hospitals and like institutions. They are very unsanitary in construction and violate almost every known sanitary

requirement for a plumbing fixture. Oftentimes they are made of plain iron which corrodes and becomes foul smelling; frequently they are encased in woodwork which shuts out light and air, and that becomes filthy from deposits of soil and foul from saturation of urine; they furnish breeding places for bacteria and vermin, and worst of all, sometimes retain for hours rank and putrid substances that should be immediately removed from sense of sight and smell. Water closets are made that are particularly adapted for hospital barracks, schools and public toilet rooms, where great strength and durability are required in a fixture, and one that can easily be cleansed with hose and broom without damage to any part. These closets can be had in washdown or siphon-jet types.

TABLE XCVIII. Size of Pipe for Single Flush Valve

Minimum Pressure at the Flush Valve	Total feet of supply pipe from the flush valve to the street main or storage tank									
	5	10	20	30	40	60	80	100	150	200
	Size of pipe for one water closet									
5 Pounds	1¼	1½	1½	1½	2	2	2	2½	2½	3
10 Pounds	1	1¼	1½	1½	1½	1½	2	2	2½	2½
20 Pounds	1	1	1¼	1¼	1¼	1½	1½	1½	2	2
30 Pounds	1	1	1	1¼	1¼	1¼	1½	1½	1½	1½
40 Pounds	1	1	1	1	1¼	1¼	1¼	1½	1½	1½
60 Pounds	¾	1	1	1	1	1¼	1¼	1¼	1½	1½
80 Pounds	¾	¾	1	1	1	1	1¼	1¼	1¼	1½

Add 10 feet for each 90 degree fitting.

VENTILATION OF CLOSET COMPARTMENTS.—Rooms in which water closets are situated should be well ventilated to insure a frequent change of air. This requirement is absolute in large toilet rooms containing many washout or other non-deodorizing closets.

A method of ventilating closet compartments is shown in Fig. 160. The separate flues in this system should never be less than 6 inches in diameter, and when possible to place a small steam or hot water coil in the bottom of each flue, the direction of the current of air is made positive. Ventilation flues from different compartments should extend

separately through the roof or be joined at considerable distance from the rooms. When joined to flues from adjoining rooms they serve as sound conductors from one room to another.

In case the water closets are of the siphon type, or of any design which contains a large volume of water and but little soiling surface, ventilation of the room will be all that is necessary, the vent registers being located back of the closets. If for any reason the toilet room is so located that the air is heavy and the ventilation consequently sluggish, or if it is approached by descending a few steps into the room, each closet of whatever type, should be vented through a local vent having at least eight square inches of area, and connected to a shaft having a positive draft insured by mechanical means. In many cases it is better to vent the closets, or the room through the local vents of the closets, than to vent the rooms through registers located back of the closets; but as a rule it is better to vent the closet compartments used by girls through registers back of the closets, than to vent them through local vents in the closets.

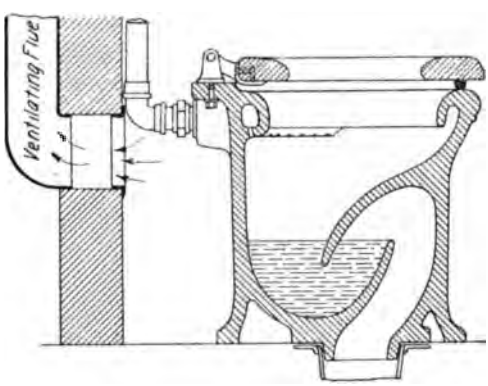


Fig. 160
Toilet Room Ventilator

URINALS.—Urinals should be made from the least absorbent and least corrosive of materials, and all exposed connections, walls, floor and partition, should be equally non-absorbent and non-corrosive. If the urinals or surroundings are absorbent they will soon become saturated with urine and emit a most pungent and disagreeable odor. If made of corrosive materials they will be energetically attacked and destroyed by the urine. Stall urinals of

vitreos ware are the most satisfactory, or the least objectionable, and are best flushed with a foot valve.

SLOP SINKS.—A slop sink at which to draw water for scrubbing and general cleaning and in which to empty soiled scrubbing water and other slops, should be provided in every building. In a residence a slop sink on the second floor will often save the cost of the fixture by protecting the bath tub and water closet from the wear and tear incident to using them for drawing and emptying scrub water and slops. Hotels, office buildings and other large institutions should have one or more slop sinks on each floor, and in hospitals slop sinks are indispensable on all floors.

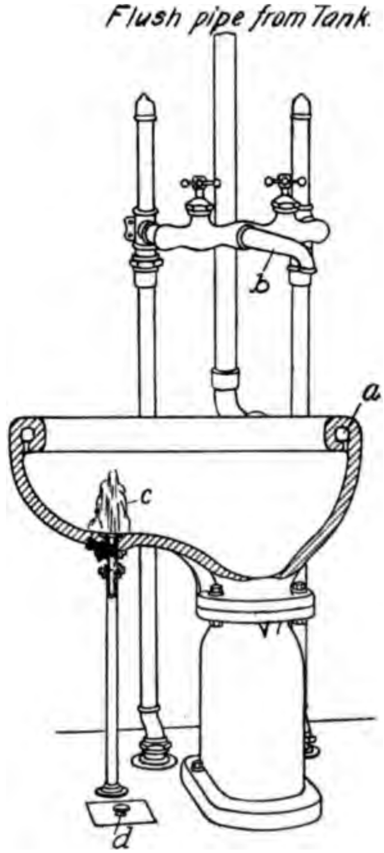


Fig. 161
Hospital Slop Sink

It is evident from the uses of a slop sink that it should be supplied with hot and cold water, and in addition, hospital slop sinks should be flushed from an overhead tank or from a flush valve. The contents of bed-pans are emptied into hospital sinks, so that to a certain extent they partake of the functions of a water closet and must therefore be made and operated like one. The outlet to slop sinks should be unobstructed by strainers or cross bars, so the waste pipe will receive a good flush. In the case of hospital sinks this requirement is absolute, on account of their dual function. As they are in the nature of water closets they should like-

wise be provided with flexible metal-to-metal floor flanges.

Slop sinks are usually made 10 to 12 inches deep and from 20 to 24 inches square. They are made both of iron and of porcelain. Iron slop sinks are made either plain, galvanized or porcelain enameled.

HOSPITAL SLOP SINKS.—A hospital slop sink is shown in Fig. 161. The bowl of the sink is shaped like a closet bowl converging toward the outlet, which is large and unobstructed by a strainer. The sink is flushed through a flushing rim, *a*, from a tank overhead or from a flush valve, and is also supplied with hot and cold water through a combination cock, *b*. The slop sink is also fitted with a cleansing jet, *c*, to which the water may be turned on by hand valves at the back of the sink or by the foot valve, *d*, on the floor. The nurse or orderly empties the contents of a bed-pan on the right side of the sink which is flushed from the tank, the bed-pan is then inverted and held over the cleansing jet in the left side of the bowl to be washed.

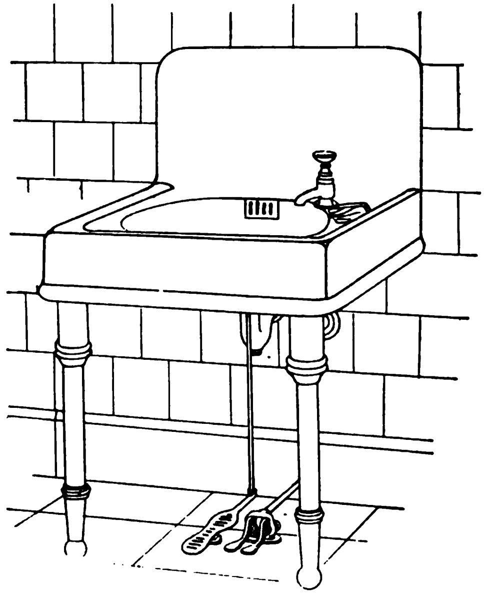


Fig. 162
Hospital Lavatory

HOSPITAL LAVATORY.—A lavatory suitable for hospital operating rooms is shown in Fig. 162. A hospital lavatory differs from a common type only in the manner of operating the supply and waste valves. This is accomplished by means of levers attached to the floor and operated by foot. A hospital lavatory should be supplied with

hot and cold water through a combination cock so that water of any desired temperature can be drawn.

SHOWER AND RAIN BATHS.—For use in private homes, public and semi-public bathing establishments, shower and spray baths, Fig. 163, are very suitable. They are always ready and permit the bather to wash in running water. Many designs of rain, shower and needle-shower and spray baths are made, some simple and some elaborate. Stock fixtures can be supplied to fill most any requirement. Mixing chambers, *a*, should be used with shower baths so the water can be tempered to the required temperature before using. When a mixing chamber is omitted, the supply valves should be so arranged that hot water cannot be turned on without also turning on the cold water. This arrangement of valves will prevent bathers from being scalded by hot water. Shower baths are often a failure, not because the shower baths are not properly made, but because they are installed without a sufficient supply of water, or without sufficient pressure. Sometimes they are lacking in both pressure and volume. As a rule it may be stated that no large needle shower and spray

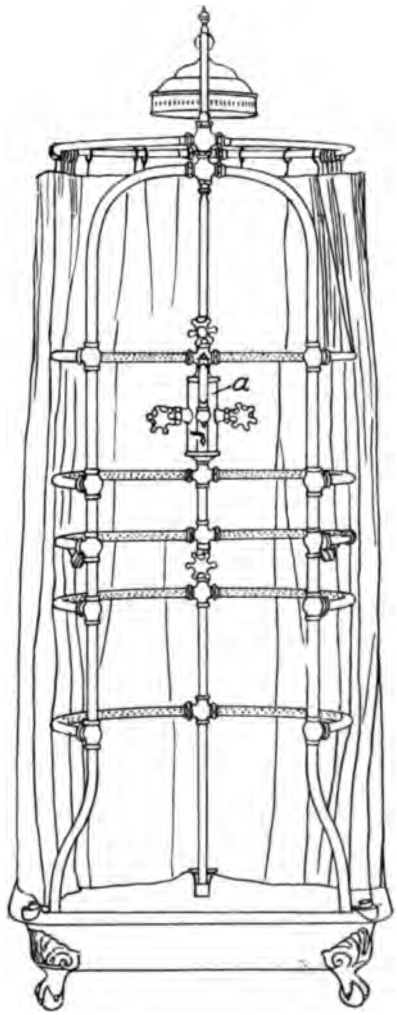


Fig. 163
Needle Shower and Spray Bath

bath will work satisfactorily with a less pressure than 20 or 25 pounds, and a supply of the full size of the fixture connections capable of delivering from 30 to 40 gallons of water per minute. Even then they will not work unless the whole water supply system is so proportioned that there will not be a drop of pressure below the 20-pound limit when other fixtures in the building are being operated. Where showers are fitted up in battery, the supply mains to them must be sufficiently large so the throwing into service or cutting out of either the hot or cold water of one will not affect the others. Small pipes are the cause of many failures of showers. Unless the supply mains are properly proportioned, when a bather has the water for his shower tempered to the right degree, it is suddenly made either hotter or colder by another shower being turned on or shut off. This will happen even when mixing valves are used, although the fluctuation of temperature will not be noticeable if the system is rightly proportioned, or a Leonard type of thermostatic mixing valve used. A hand on this valve is set at the temperature of water wanted and the variation from that temperature will not be more than two degrees.

A great mistake in institutional work where a number of showers are to be used, is in getting the shower heads too large in diameter and with the perforation or holes too large and too numerous. This is unnecessary from a practical standpoint, for a small shower head with small holes will give as good results; and it is wasteful from an economic standpoint, for it will use too much water, part of which has to be heated. By actual measurement, it was found that one shower head was using water at the rate of 35 gallons per minute.

In practice it is found that a shower head 4 inches in diameter, having 70 holes of about 1/32-inch each, is large enough for all the ordinary requirements of institution or other shower work, and is at the same time particularly saving of water. This size shower head operates very satisfactorily at a low head or pressure, owing to the increased velocity obtained by the use of small spray holes.

It is found that a ¾-inch pipe with water at 50 pounds

pressure will supply six 4-inch shower heads each having 70 holes of 1/32-inch diameters. That is the very smallest supply for that number, and, even at the pressure stated is inclined to be small. That is, it would be better for six shower heads of the kind described to provide larger supplies, and as the pressure decreases, increase the size still more.

CHAPTER XXXII

SWIMMING POOLS

CONSTRUCTION OF SWIMMING POOLS.—The structural features of a swimming pool depend somewhat upon the place where it will be located, and particularly on whether it will rest on solid foundation or be suspended from the steel floor beams of a building.

A swimming pool, or plunge bath, built on a solid foundation of earth or bed rock can be seen in Fig. 164. It is made of reinforced concrete with walls of a thickness proportional to the size and depth of the tank. The concrete would be poured wet, and mixed with an integral water-

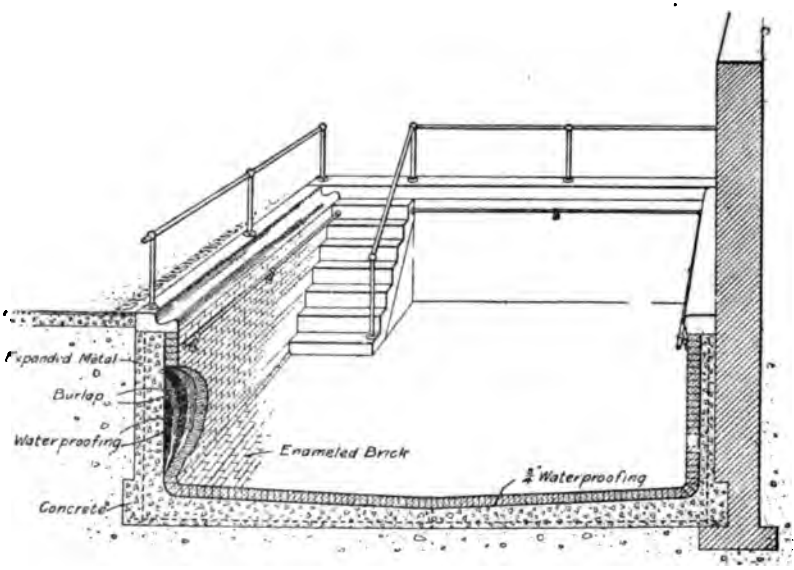


Fig. 164
Plunge Tank

proofing compound. In addition, the bottom and walls would be water proofed by applying a coating of asphalt, or some other good water proofing material, about ½-inch thick, laid hot in burlap of 8 to 12 ounce weight, then while still hot covered with another ½-inch of the water proofing

material and burlap pressed and broomed to a proper bond.

Where pipes pass through the walls or bottom they must be made water tight by means of lead flashings built into the concrete, and water proofing.

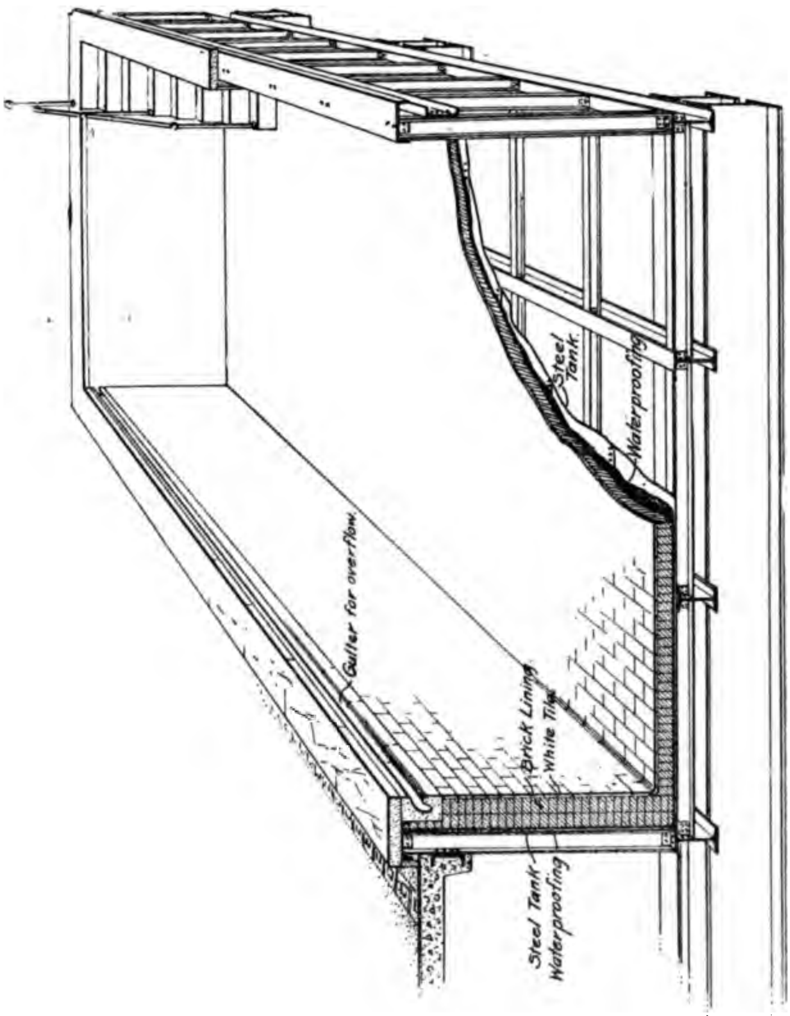


Fig. 165
A Hanging Plunge Bath

After the walls have been water proofed, the tank may then be lined with an 8-inch wall of glazed brick. A 4-inch wall may be used if there is no danger of back pressure from

ground water at the site; or instead of using brick, the water proofing material may be laid between two walls of concrete, and the inner surface lined with tile.

The bottom of a swimming pool is made sloping, so there will be good drainage towards one point, and so the tank will be deeper at one end than at the other. In small tanks the depth at the shallow end will average between $3\frac{1}{2}$ and 4 feet, and 5 to 6 feet at the deep end. In large plunge baths a depth of 7 to 8 feet will be found at the deep end.

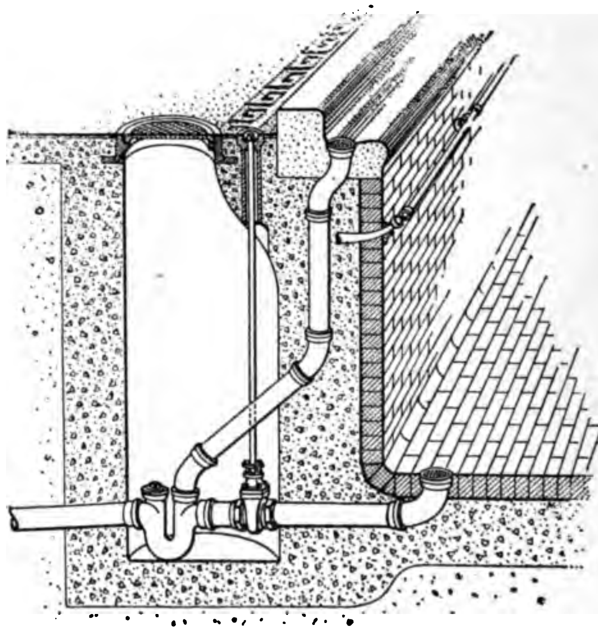


Fig. 166
Waste Connected to Plunge Tank

A gutter is shown at the surface level of the water. This gutter extends around all sides of the pool, serving as an overflow. Also by turning on the water the top scum or film can be skimmed off, thereby carrying off floating impurities from the surface. A railing is shown about a foot below the level of the gutter.

A hanging or suspended swimming pool is shown in Fig. 165. The details of construction are very clearly

shown. The bearing walls of the building must be made strong enough to sustain the tremendous weight of the pool when it is filled with water, and double I beams will be required at frequent intervals to support the frame work of the tank. The framework is made of I beams and channel irons, and inside of the framework a steel tank is built as a casing for the plunge. This tank must be made of sufficiently heavy plates to sustain the weight of lining and water without bending or yielding between supports. The inside of the tank is water proofed and lined as explained in the case of tanks resting on the ground.

The waste and overflow connections to a swimming pool is shown in Fig. 166. The overflow pipe is made large enough to carry off as much water as can be discharged into the tank by the supply pipes, and the waste pipe is made large enough to empty the tank inside of an hour.

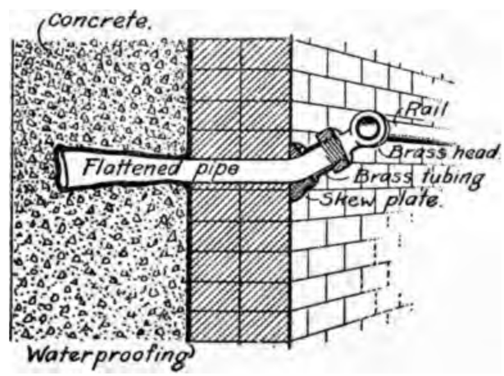


Fig. 167
Hand Rail Support

Sometimes swimming pools are located below the level of the street sewer, in which case the contents of the tank must be elevated to the sewer when emptying by means of pumps. Ordinarily a centrifugal pump direct-connected to an electric motor is used for this purpose.

One method of attaching anchors for the support of hand rails is shown in Fig. 167. A piece of pipe flattened at one end to keep from turning and threaded and bent at the right angle, is built into the wall. Then when the glazed brick or tile are in place the rail can be finished by putting the cast brass skew plates on the anchor pipes, then screwing into place the cast brass ring heads.

Heating Water for Swimming Pools.—The water in

a swimming pool is generally heated by circulating it through a steam water heater. Sometimes when the pool is at a higher level than the boiler room, a simple gravity system of heating by means of a coal water heater such as is shown in Fig. 168 is employed. The cold water supply is connected to the heater, and by-passed to the pool, so water can be supplied direct or through the heater. In very small tanks only one inlet and outlet connection will be necessary, but in large tanks multiple connections give a better distribution and circulation of the water.

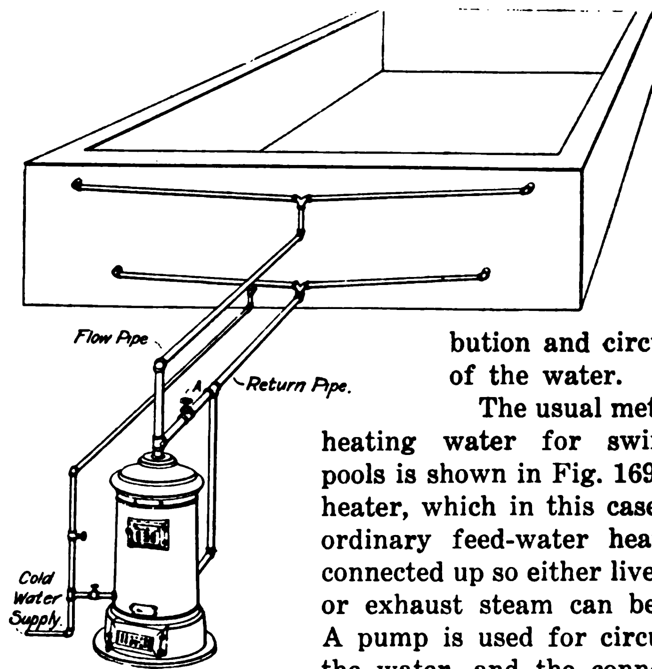


Fig. 168
Heating Plunge with Water Heater

The usual method of heating water for swimming pools is shown in Fig. 169. The heater, which in this case is an ordinary feed-water heater, is connected up so either live steam or exhaust steam can be used. A pump is used for circulating the water, and the connections to the pump are cross connected to the sewer, so the water from the pool can be discharged by the pump into the city sewer.

STERILIZATION OF SWIMMING-POOL WATER.—The water in a swimming pool becomes contaminated very quickly when in use, each bather contributing some towards this state of affairs. Serious infections have been traced directly to unsanitary pools. The Detroit Board of Health took weekly samples of a pool for a period of one year. During

this time filtration and chemical disinfection were used. The result showed a maximum count of 216,000 colonies of bacteria per cubic centimeter—a cubic centimeter is about 15 drops—and an average count of 26,706 colonies per cubic

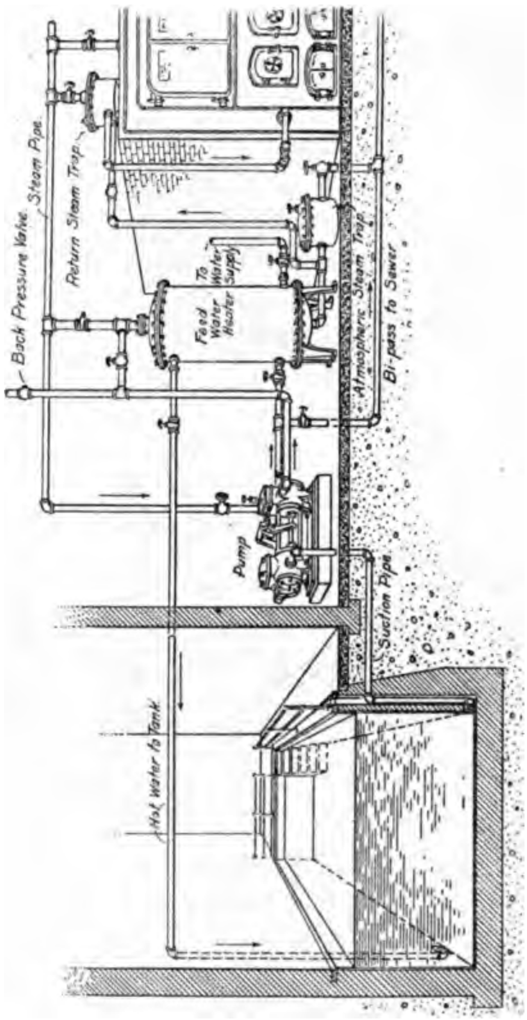


Fig. 169
Heating Plunge with Feed-Water Heater

centimeter. All samples showed gas indicating colon bacilli.

The water in a swimming pool ought to contain not more than 1,000 colonies per cubic centimeter. There is no

standard established as yet, however, so the practice lacks uniformity. The California State Board of Health offers the following as a standard for the bacterial purity of water in swimming pools, which will answer until a national standard is adopted:

"All the water in the pool and applied to the pool shall

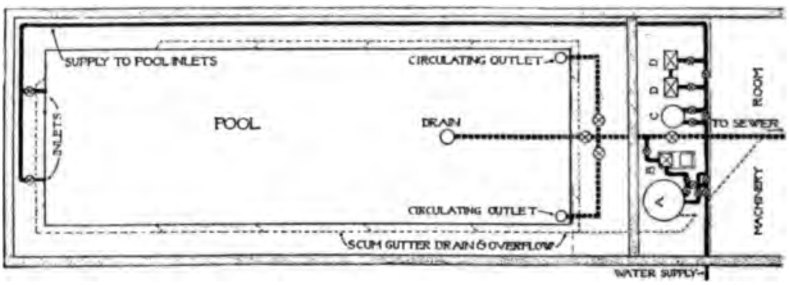


Fig. 170
Swimming Pool Plan

be continuously safe hygienically. As a tentative standard, a total bacterial count of 1,000 colonies per cubic centimeter on agar, incubated at 37.5 degrees C., and a B. Coli count of 1 per cubic centimeter, is set for the pool water in any part of the pool examined within 48 hours after sampling.

"All tests are to be made in accordance with the latest

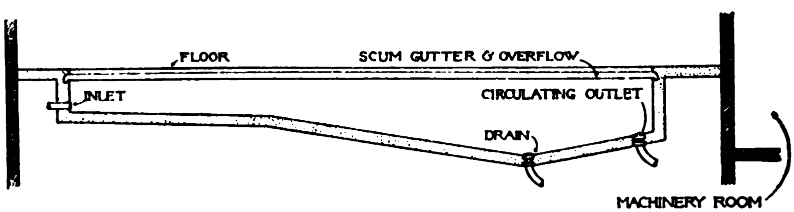


Fig. 171
Swimming Pool Section

methods of the American Public Health Association."

The dilution method is now generally employed to maintain the purity of the water in a swimming pool. The dilution method consists of supplying a water that is originally pure, distributing that water evenly and uniformly throughout the tank, and supplying it in sufficient quantity to insure

frequent changes of the water in the pool. This is done by recirculating the water through cleansing and heating apparatus, and back again to the pool.

In Fig. 170 is shown the plan of a swimming pool, and in Fig. 171 a section through the same pool. In Fig. 172 can be seen the layout of apparatus serving the pool. Reference letters refer to all three illustrations. It will be observed that the inlets are at one end of the tank, and the outlets at the other. Water is drawn from the pool and

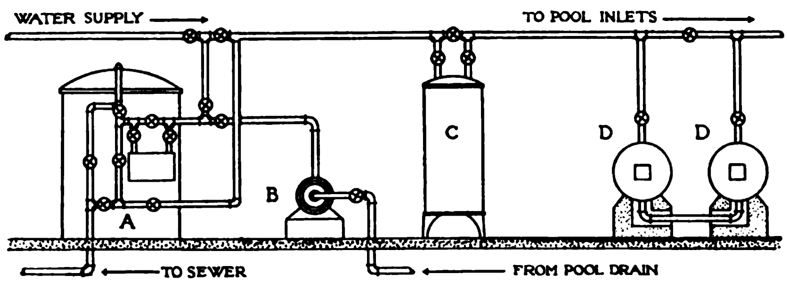


Fig. 172
Lay-out of Apparatus Serving Pool

forced through the filter, A, by means of pump, B. From the filter the water flows to the heater, C, or is by-passed around the heater if the water is warm enough. From the heater it flows through a battery of two ultra violet ray sterilizers, which are generally used for the sterilizing of water in swimming pools. The filters clarify the water, the heater heats it, and the ultra violet ray apparatus sterilizes the water. The apparatus is so connected that new water from the city mains can be made pass through filter, heater and sterilizer before discharging into the pool.

CHAPTER XXXIII

APPENDIXES

DECIMAL FRACTIONS OF A FOOT.—Measurements expressed in fractions of an inch can be converted into decimal fractions of a foot by the following rule:

Rule—Multiply the measurement expressed in fractions of an inch by 1/12, and divide the numerator of the product by the denominator; the quotient will be the corresponding fraction of a foot expressed as a decimal.

EXAMPLE—Reduce ¾ inch to a decimal fraction of a foot.

SOLUTION—$3/4 \times 1/12 = 3/48 = .0625$. Answer.

For convenience in reference, Table XCIX of decimal equivalents of a foot for each 1/64 of an inch is appended.

Decimal fractions of a foot can be converted to common fractions of an inch by reducing the decimal to a common fraction of lowest denomination and dividing it by 1/12.

EXAMPLE—Reduce .0625 of a foot to a fraction of an inch.

SOLUTION—$.0625 = \frac{625}{10000} = 1/16$, and $1/16 \div 1/12 = 3/4$. Answer.

DECIMAL EQUIVALENTS OF AN INCH.—Measurements that are expressed in fractions of an inch can be converted into decimal fractions by dividing the numerator by the denominator.

EXAMPLE—What is the decimal equivalent of ⅛ of an inch?

SOLUTION—$1/8 = 1 \div 8 = .125$. Answer.

Fractions of an inch expressed as decimals can be converted to common fractions of an inch by changing the decimal to a common fraction, and then reducing it to its lowest terms. Decimals can be changed to common fractions by using the decimal for a numerator, and writing below it for denominator 1, with as many ciphers annexed as there are decimal places in the numerator.

EXAMPLE—Reduce .125 to a common fraction.

SOLUTION—$.125 = \frac{125}{1000} = 1/8$. Answer.

TABLE XCIX. Decimals of a Foot for Each 1/64 of an Inch

Inch	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
0	0	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
	.0013	.0846	.1680	.2513	.3346	.4180	.5013	.5846	.6680	.7513	.8346	.9180
1-32	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
	.0039	.0872	.1706	.2539	.3372	.4206	.5039	.5872	.6706	.7539	.8372	.9206
1-16	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
	.0065	.0898	.1732	.2565	.3398	.4232	.5065	.5898	.6732	.7565	.8398	.9232
3-32	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	.9245
	.0091	.0924	.1758	.2591	.3424	.4258	.5091	.5924	.6758	.7591	.8424	.9258
1-8	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
	.0117	.0951	.1784	.2617	.3451	.4284	.5117	.5951	.6784	.7617	.8451	.9284
5-32	.0130	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
	.0143	.0977	.1810	.2643	.3477	.4310	.5143	.5977	.6810	.7643	.8477	.9310
3-16	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
	.0169	.1003	.1836	.2669	.3503	.4336	.5169	.6003	.6836	.7669	.8503	.9336
7-32	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
	.0195	.1029	.1862	.2695	.3529	.4362	.5195	.6029	.6862	.7695	.8529	.9362
1-4	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
	.0221	.1055	.1888	.2721	.3555	.4388	.5221	.6055	.6888	.7721	.8555	.9388
9-32	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
	.0247	.1081	.1914	.2747	.3581	.4414	.5247	.6081	.6914	.7747	.8581	.9414
5-16	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
	.0273	.1107	.1940	.2773	.3607	.4440	.5273	.6107	.6940	.7773	.8607	.9440
11-32	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
	.0299	.1133	.1966	.2799	.3633	.4466	.5299	.6133	.6966	.7799	.8633	.9466
3-8	.0312	.1146	.1979	.2812	.3646	.4479	.5312	.6146	.6979	.7812	.8646	.9479
	.0326	.1159	.1992	.2826	.3659	.4492	.5326	.6159	.6992	.7826	.8659	.9492
13-32	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
	.0352	.1185	.2018	.2852	.3685	.4518	.5352	.6185	.7018	.7852	.8685	.9518
7-16	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531
	.0378	.1211	.2044	.2878	.3711	.4544	.5378	.6211	.7044	.7878	.8711	.9544
15-32	.0391	.1224	.2057	.2891	.3724	.3557	.5391	.6224	.7057	.7891	.8724	.9557
	.0404	.1237	.2070	.2904	.3737	.4570	.5404	.6237	.7070	.7904	.8737	.9570

TABLE XCIX—Continued

Inch	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
1–2	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
	.0430	.1263	.2096	.2930	.3763	.4596	.5330	.6263	.7096	.7930	.8763	.9596
17–32	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
	.0456	.1289	.2122	.2956	.3789	.4622	.5456	.6289	.7122	.7956	.8789	.9622
9–16	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
	.0482	.1315	.2148	.2982	.3815	.4648	.5482	.6315	.7148	.7982	.8815	.9648
19–32	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
	.0508	.1341	.2174	.3008	.3841	.4674	.5508	.6341	.7174	.8008	.8841	.9674
5–8	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
	.0534	.1367	.2201	.3034	.3867	.4701	.5534	.6367	.7201	.8034	.8867	.9701
21–32	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	.8880	.9714
	.0560	.1393	.2227	.3060	.3893	.4727	.5560	.6393	.7227	.8060	.8893	.9727
11–16	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
	.0586	.1419	.2253	.3086	.3919	.4753	.5586	.6419	.7253	.8086	.8919	.9753
23–32	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
	.0612	.1445	.2279	.3112	.3945	.4779	.5612	.6445	.7279	.8112	.8945	.9779
3–4	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
	.0638	.1471	.2305	.3138	.3971	.4805	.5638	.6471	.7305	.8138	.8971	.9805
25–32	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
	.0664	.1497	.2331	.3164	.3997	.4831	.5664	.6497	.7331	.8164	.8997	.9831
13–16	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
	.0690	.1523	.2357	.3190	.4023	.4857	.5690	.6523	.7357	.8190	.9023	.9857
27–32	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
	.0716	.1549	.2383	.3216	.4049	.4883	.5716	.6549	.7383	.8216	.9049	.9883
7–8	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
	.0742	.1576	.2409	.3242	.4076	.4909	.5742	.6576	.7409	.8242	.9076	.9909
29–32	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
	.0768	.1602	.2435	.3268	.4102	.4935	.5768	.6602	.7435	.8268	.9102	.9935
15–16	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
	.0794	.1628	.2461	.3294	.4128	.4961	.5794	.6628	.7461	.8294	.9128	.9961
31–32	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974
	.0820	.1654	.2487	.3320	.4154	.4987	.5820	.6654	.7487	.8320	.9154	.9087
1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.0000

Decimal equivalents of fractions of an inch can be found in Table C.

TABLE C. Decimal Equivalents of Fractions of an Inch

8ths	9/16=.5625	17/32=.53125	9/64=.140625	37/64=.578125
1/8 = .125	11/16=.6875	19/32=.59375	11/64=.171875	39/64=.609375
1/4 = .250	13/16=.8125	21/32=.65625	13/64=.203125	41/64=.640625
3/8 = .375	15/16=.9375	23/32=.71875	15/64=.234375	43/64=.671875
1/2 = .500		25/32=.78125	17/64=.265625	34/64=.703125
5/8 = .625	32ds	27/32=.84375	19/64=.296875	47/64=.734375
3/4 = .750	1/32=.03125	29/32=.90625	21/64=.328125	49/64=.765625
7/8 = .875	3/32=.09375	31/32=.96875	23/64=.359375	51/64=.796875
	5/32=.15625		25/64=.390625	53/64=.828125
16ths	7/32=.21875	64ths	27/64=.421875	55/64=.859375
1/16=.0625	9/32=.28125	1/64=.015625	29/64=.453125	57/64=.890625
3/16=.1875	11/32=.34375	3/64=.046875	31/64=.484375	59/64=.921875
5/16=.3125	13/32=.40625	5/64=.078125	33/64=.515625	61/64=.953125
7/16=.4375	15/32=.46875	7/64=.109375	35/64=.546875	63/64=.984375

DECIMALS OF A SQUARE FOOT.—Measurements taken in square inches can be converted into decimals of a square foot by dividing the number of square inches by 144, which is the number of square inches contained in a square foot.

EXAMPLE—Express 20 square inches as a decimal of a square foot.

SOLUTION—20 square inches $= \frac{20}{144} = 20 \div 144 = .138$. Answer.

Square inches expressed as decimals of a square foot can be found in Table CI.

To reduce decimals of a square foot to square inches, multiply the decimal by 144.

EXAMPLE—Reduce .1388 of a foot to square inches.

SOLUTION—$.1388 \times 144 = 20$ square inches nearly. Answer.

AREA OF A CIRCLE.—To find the area of a circle, square the diameter and multiply by .7854. Squaring the diameter means multiplying the length of the diameter by itself.

EXAMPLE—What is the area of a circle having a diameter of 20 feet?

SOLUTION—$20 \times 20 \times .7854 = 314.16$ square feet. Answer.

DIAMETER OF A CIRCLE.—When the area of a circle is known, the diameter can be found by dividing the area by .7854 and extracting the square root.

EXAMPLE—What is the diameter of a circle having an area of 314.16 square feet?

SOLUTION—$314.16 \div .7854 = 400$ and $\sqrt{400} = 20$ feet. Answer.

TABLE CI. Square Inches in Decimals of a Square Foot

Square Inch	Square Foot	Square Inch	Square Foot	Square Inch	Square Foot	Square Inch	Square Foot
1	.00694	15	.10416	29	.20138	43	.29861
2	.01388	16	.11111	30	.20833	44	.30555
3	.02083	17	.11805	31	.21527	45	.31249
4	.02777	18	.12500	32	.22222	46	.31944
5	.03472	19	.13194	33	.22916	47	.32638
6	.04166	20	.13888	34	.23611	48	.33333
7	.04861	21	.14583	35	.24305	49	.34027
8	.05555	22	.15277	36	.25000	50	.34722
9	.06250	23	.15972	37	.25694	51	.35416
10	.06944	24	.16666	38	.26388	52	.36111
11	.07638	25	.17361	39	.27083	53	.36805
12	.08333	26	.18055	40	.27777	54	.37500
13	.09027	27	.18750	41	.28472	55	.38194
14	.09722	28	.19444	42	.29166	56	.38888
57	.39583	79	.54861	101	.70138	123	.85416
58	.40277	80	.55555	102	.70833	124	.86111
59	.40972	81	.56249	103	.71527	125	.86805
60	.41666	82	.56944	104	.72222	126	.87500
61	.42361	83	.57638	105	.72916	127	.88194
62	.43055	84	.58333	106	.73611	128	.88888
63	.43750	85	.59027	107	.74305	129	.89583
64	.44444	86	.59722	108	.75000	130	.90277
65	.45138	87	.60416	109	.75691	131	.90972
66	.45833	88	.61111	110	.76388	132	.91666
67	.46527	89	.61805	111	.77083	133	.92361
68	.47222	90	.62500	112	.77777	134	.93055
69	.47916	91	.63194	113	.78472	135	.93750
70	.48611	92	.63888	114	.79166	136	.94444
71	.49305	93	.64583	115	.79861	137	.95138
72	.50000	94	.65277	116	.80555	138	.95833
73	.50694	95	.65972	117	.81249	139	.96527
74	.51388	96	.66666	118	.81944	140	.97222
75	.52083	97	.67361	119	.82638	141	.97916
76	.52777	98	.68055	120	.83333	142	.98611
77	.53472	99	.68750	121	.84027	143	.99305
78	.54166	100	.69444	122	.84722	144	1.00000

Life of Cast Iron Pipes

The question often arises, how long will cast iron pipe last when buried in the earth. This question cannot be

answered definitely in any case, for the life of a cast iron pipe will depend upon the chemical composition of the earth and water it is in contact with, the chemical constituents of the fluid passing through, and whether or not the pipe is covered with a protective coating. The following data, however, will serve as a guide in forming a judgment.

The only data from observations at hand are found in reports from St. John, N. B., and Los Angeles, Cal. The superintendent of the water works at the former place reported in 1892 several observations. In one case a 4-inch main, in use about 33 years in marsh mud, had failed by softening of the outside, and the break took place at some air cells in the body of the pipe.

A 6-inch pipe 52 years old in soft, slaty rock, failed from softening. A 24-inch pipe laid in well drained, gravelly brick clay, 36 years old, failed from inherent defects in the pipe, the outside of the pipe being sound and the inside having a coat less than 1/16 inch thick. None of these pipes were protected by coatings. The conclusion regarding the 24-inch pipe in well drained gravelly clay was that, aside from the defects in manufacture, its life would have been practically indefinitely long.

The City Engineer of Los Angeles, Cal., reported the condition of the water works in 1897. The pipe was uncovered in 318 places. Cast iron pipe 28 years old was found in a perfect state of preservation. In sand or loam the bare pipe metal did not rust. In hard adobe soil there was some rust, but the pipe was practically uninjured. In all cases the original asphalt coating had practically disappeared. A later report of a board of engineers, estimated the depreciation of the water pipe in the city in the better soils at 1.25 per cent. per annum, indicating a life of 80 years, and in the poorer soils at 2 per cent. per annum, indicating a life of 50 years. The effect of the soil upon the outside of the pipe and of tuberculation upon the inside are both allowed for in these estimates.

In case there is opportunity for electrolysis from street railway or other electric leakage, the life of pipe is very

greatly shortened. Some chemical conditions of soil which will shorten the life of pipe will doubtless also be met with.

Length of Life of Wrought Iron Gas Pipe

Like with cast iron pipe buried in the ground, any statement about wrought pipe that would be correct in one locality might be entirely wrong in another, its life depending largely upon the chemical composition of the land through which it runs. There are cases where pipes which had been in but 10 years, upon examination were found to be badly decomposed, while in another locality which pipe that had been under ground 25 years when uncovered showed but little signs of decay. This refers to the outside surface only. Cases are rare, however, when pipe would be so affected in 10 years as to require replacing. While chemical action figures largely in considering this question it is not the only thing to take into account when considering the life of gas pipe. Electrolysis is liable to be more destructive in its attacks than the ordinary chemicals of the earth. It will be seen, therefore, that it is quite impossible to give any definite data on the subject, but under ordinary circumstances cutting out the possibilities of electrolysis and especially corrosive soil, 25 years would be about as long a life as the average underground gas pipe would last, so far as outside deterioration is concerned. When the inner surface is considered, however, an entirely different problem is presented. There we have the quality of the gas to consider.

For instance, gas pipes which for years gave perfect satisfaction, while coal gas was being distributed, became entirely useless from the effects of the gas, when adulterated gas was forced through the mains, naphthalene and rust accumulating to such an extent as to stop the flow of gas entirely. As a rule gas pipes suffer more from the inside than the outside, particularly in the case of small pipes where the impurities and condensation have a better chance to work on the entire surface, making small pipes shorter-lived than the larger ones.

And while a good sized pipe might be in fairly good

condition at the age of 25, the smaller sized might be filled with rust and condensation and be condemned at 15. Under favorable conditions, good gas, etc., there is no reason why pipe of sufficient sizes should not be good for 25 years at least, conducting either gas or water.

The Sherardizing Process

The process of sherardizing metals is becoming so extensively used in the manufacture of plumbing materials, that a better knowledge of the process should be had by all engaged in the business.

In the course of some extensive experiments, writes Thomas Liggett in *The Foundry,* for the purpose of improving case-hardening methods, early in the twentieth century, Dr. Sherard Copew-Cowles sprinkled some zinc dust on a piece of steel and subjected the whole to the ordinary case-hardening process and at a temperature less than the melting point of zinc—less than 788 degrees Fahrenheit. When the material cooled, he found that the steel was coated with a thin layer of zinc. After thorough and exhaustive tests it was found that this coating gave the underlying metal better protection than that obtained by the well known hot process, or galvanizing as this is known.

The essential apparatus necessary in a sherardizing plant is an oven large enough to receive the retorts or drums which contain the material to be treated. The largest retorts in use today are 26 inches in diameter and 23 feet long, designed for merchant pipe. The retorts are loaded with the material to be treated and zinc dust or dross, placed in the oven and subjected to the heat from any of the common fuels, providing that an even temperature may be maintained. The retorts are left in the oven for a short period at a constant temperature and then removed. When they can be handled, they are opened and the material and unused dust are dumped on a screen or grating. The dust falls through and is ready to be used again. The material is finished and found to be covered with a continuous, uniform coating of zinc iron alloy, with a very thin coating of metallic zinc on the surface.

No matter how irregular the shape of the material, it has a uniform coating and everything is reproduced.

An inconsiderable amount of superficial material is added by the sherardizing process. The zinc dust which is used in the process is a secondary product from a zinc smelter and is recovered in the flues. The dust is composed of from 85 to 92 per cent. metallic zinc, about 7 per cent. zinc oxide and some other impurities which are not in sufficient quantities to work any injury. Zinc dross also can be used instead of dust and it has its advantages. It is the material which settles to the bottom of a galvanizing kettle. After treating it, no difficulty is found in pulverizing it for use. While there have been several theories advanced as to the action which takes place in the retorts or drums during the process, the following facts alone are known:

If metallic zinc content in the dust is kept constant there is on the same class of materials equal weights of coating, under the same temperature and time of treatment.

Zinc does not begin to deposit until the material has reached the temperature at which magnetic oxide of iron appears.

Iron which oxidizes with difficulty, sherardizes with difficulty.

The continuity of the zinc dust coating, when properly applied, is equal to and in the majority of cases superior to the hot galvanized coating. While, it is true, under the microscope the zinc iron alloy shows cracks or fissures, these are of such minute dimensions that nothing can get through to the underlying metal.

The adherence of this alloy is very tenacious. The durability of the alloy coating is great, although it is a little more brittle than pure zinc and has a slight tendency to flake if bent through a sharp angle. The metal which is exposed after the flaking is still resistent to corrosion, which shows that the underlying metal is not exposed. The resistance of the alloy to corrosive agencies is much greater than with the zinc coating. In testing sherardized material the method most frequently used is the Preece or copper

sulphate method. This consists of immersing a piece of galvanized material in a standard copper sulphate solution for one minute then washing in clear water and drying with cotton waste. This is repeated four times, and if there are no bright metallic copper deposits, the material is accepted. The standard solution is one whose specific gravity at 65 degrees Fahrenheit is 1.186. It is prepared by dissolving copper sulphate in water, to which an excess of cupric oxide has been added. This solution is then filtered and the specific gravity made 1.186 at 65 degrees Fahrenheit. The trouble of testing sherardized material by this method is that if the material is wiped with waste a burnishing action takes place. The reasons for this are that the sherardized coating being an alloy, the copper is deposited more slowly and is more adherent than that which deposits on hot galvanized material; as the sherardized surface is rough it affords a foothold for this copper and the waste rubbing the top burnishes the copper so that instead of cleaning the surface as the specifications intend, the deposit is rubbed onto the object. With further dipping, the copper deposit thickens, and those not thoroughly familiar with this action will decide that the coating has failed. To overcome this, it is always best to use a stiff bristle brush and scrub lightly instead of using waste.

The Cost of Digging

The plumber has so much digging and refilling of trenches for his pipes, that the following data as to costs will be convenient. In laying sewers and water-mains, men will excavate and throw on the bank 10 cu. yds. of sand or easy earth and from that down to 6 cu. yds. of very hard picking earth in a day of eight hours. In back-filling with shovels, any good workman should average from 12 to 16 cu. yds. in eight hours. For shallow work, that is trenches not more than five feet deep, the above output should be increased about 50 per cent. for excavation but the figures for backfilling maintained. If a laborer is paid $1.50 for 8 hours' work and can put out 8 cu. yds. of earth, the cost will be a trifle under 19 cents for digging. The cost of

backfilling will be about 12 cents, thus making the total cost per yard only 31 cents. It is seldom that stone which must be drilled and blasted, will cost more than $2.00 per cu. yd.

Ice

Freezing of water is the cause of much trouble in plumbing systems. Burst pipes and vessels, the most common damage, is caused by the expansion of water when it turns from the fluid to the solid state. When it freezes, water increases in volume 10 per cent., so that ten volumes of water produce 11 volumes of ice. Fresh water, under ordinary circumstances, when it reaches the temperature of 32 degrees Fahrenheit, passes to the solid state, or crystalizes into ice.

Water in freezing always expands. If it be so confined that expansion is impossible, it remains liquid even at temperatures far below the freezing point; but the instant the pressure is removed, the water freezes into solid ice. As there is a constant effort on the part of water exposed to freezing temperatures to form ice, and as a very considerable pressure is needed to counterbalance its expansive force, the lower the temperature the greater the pressure becomes. At a temperature of 30 degrees Fahrenheit the pressure amounts to 146 atmospheres, or the weight of a column of ice one mile high; or 138 tons per square foot. Consequently, when water freezes at a lower temperature, the pressure on the walls of its enclosing vessel exceeds 138 tons per square foot. Bomb-shells and cannon filled with water and hermetically sealed, have been burst in freezing weather by the expansion of the freezing water within them. When water is under pressure, for every atmosphere of pressure, that is, for every 14.7 pounds to the square inch, the freezing point is lowered by .0075 degree Centigrade.

MULTIPLE SHRINKAGE OF FLOOR BEAMS.—In buildings of wooden floor construction there is more to consider than the mere shrinkage of one depth of floor joist. There is the multiple shrinkage of the several tiers of joists. Buildings

over five stories in height seldom have wooden floor beams, although up to that height they are the rule rather than the exception. If we take as an example, then, the multiple shrinkage in a three-story building, it will do to explain the case. In Fig. 173 is shown the framework of an ordinary building when properly put together. This illustration shows a row of brick piers in the centre of the building supporting a 10 x 12 girder on which rests the centre bearing partition to carry the floor beams for the upper floors.

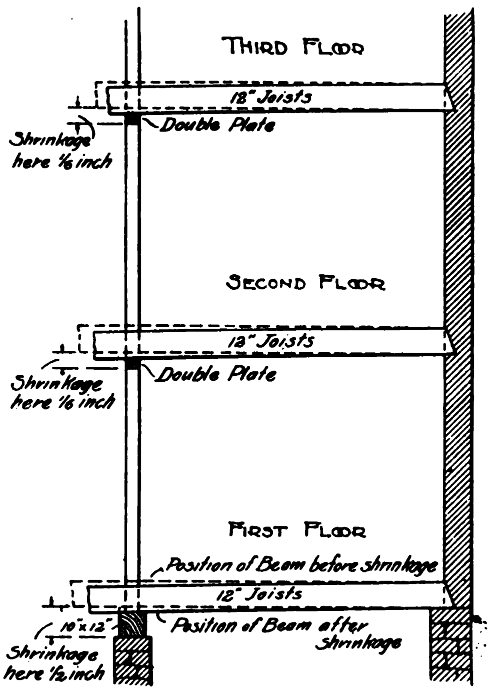


Fig. 173
Framework of an Ordinary Building
When Properly Put Together

It will be observed that each tier of beams rests on a plate made of two 2 x 4 and from this plate the studdings are erected for the next tier of beams. If the total shrinkage for the three floors be now computed it will be seen that the 10 x 12 girder has shrunk approximately ½ inch, and the two plates on which the second and third floor beams rest,

each being 4 inches deep, shrink approximately 1/6 inch each. The total shrinkage for the third floor therefore would be ½ plus 1/6 plus 1/6, equals 5/6 of an inch. The dotted line shows the original position of the joists, and the solid lines the position after shrinkage has taken place. It might be well to add that carpenters are aware of this shrinkage of timbers and in building make the floors higher in the centre than at the walls to allow for the shrinkage so the floors will be about level when the building has dried out.

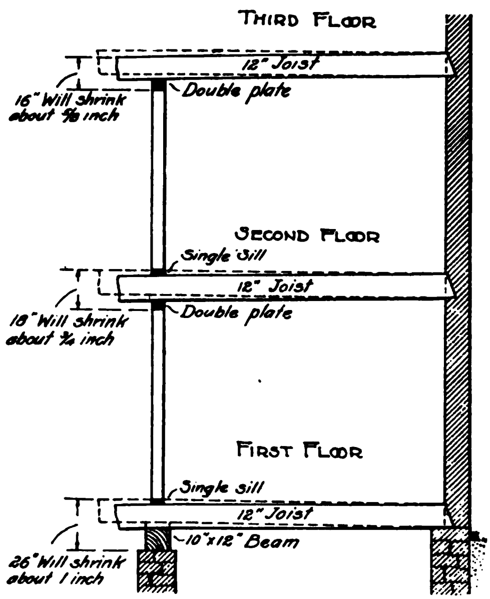


Fig. 174
Framework of a Commonly Constructed Building

But buildings are not always erected as they should be. In the illustration, Fig. 174, is shown how they commonly are constructed. This method of framing saves a foot in length of every studding at each floor, and for this reason is more often followed than the better method.

The difference to the plumber and fitter, however, will be readily seen. Instead of all floors resting on a partition supported by a girder so there would be no shrinkage to

take care of but that of the girder and two double plates (wood does not shrink lengthwise perceptibly) in the present method the bearing partitions for each floor rests on a single plate supported by the floor joists below; the result is, the upper floors are affected by the shrinkage of the floor joists on every floor below them. In the present instance, the joist, sill and girder of the first floor are 26 inches deep and will shrink all told over 1 inch. The double plate, joist and sill of the second floor being about 18 inches deep will shrink approximately $3/4$ inch; while the double plates and joists of the third floors, being 16 inches deep, will shrink about $5/8$ inch.

The total lowering of the floor line of the third floor then will be 1 plus $3/4$ plus $5/8$, equals $2 3/8$ inches, as against less than one inch in the former method of construction. It will be seen, therefore, that the plumbers and fitters in laying out their work must take into consideration not only the shrinkage of beams and timbers and their combined shrinkages, but likewise the method of construction and make due allowances in the connection to radiators, and provide flexible and collapsible connections for water closets.

Water Pipe Sizes in Various American Cities

Sir: The writer has recently compiled statistics of the amount of the several sizes of water pipe in use in the following cities:

Cambridge, Mass.	Lowell, Mass.	Fall River, Mass.
Brockton, Mass.	Attleboro, Mass.	Hartford, Conn.
Richmond, Va.	Troy, N. Y.	Washington, D. C.
Holyoke, Mass.	Concord, N. H.	Brookline, Mass.
Providence, R. I.	Corning, N. Y.	Boston, Mass.
New Haven, Conn.	Wilmington, Del.	Springfield, Mass.
Reading, Pa.	Binghamton, N. Y.	Albany, N. Y.
Worcester, Mass.	Rochester, N. Y.	Waterbury, Conn.
	New Bedford, Mass.	

As these 25 cities may perhaps be considered as representing the average of a greater number, the following result is given, as being of possible interest to your readers:

Size.	Percentage.	Size.	Percentage.
3 in.	.77	18 in.	.03
4 in.	8.93	20 in.	2.81
6 in.	44.98	24 in.	2.54
8 in.	14.44	30 in.	1.99
10 in.	4.00	36 in.	1.17
12 in.	12.64	40 in.	.30
14 in.	.42	42 in.	.20
16 in.	4.38	48 in.	.40

W. B. FRANKLIN,

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